Planning for Resilient Operations to Address Uncertainties in Water, Energy, and Waste Management and Decision-Making in the Mojave Desert: Summary of Stakeholder Engagement and Opportunities for Joint Projects and Regional Collaboration

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Acronyms and Abbreviations

ACE .... Air, Climate, and Energy
AFB .... Air Force Base
AFY .... Acre-feet per Year
ARS .... Agricultural Research Service
ASD-EI&E .... Assistant Secretary of Defense for Energy, Installations, and Environment
BMP .... Best Management Practice
BRAC .... Base Realignment and Closure
CAX .... Combined Arms Exercise
CO2 .... Carbon Dioxide
CWA .... Clean Water Act
DLA .... Defense Logistics Agency
DMG .... Desert Managers Group
DPW .... Division of Public Works
DoD .... Department of Defense
DoE .... Department of Energy
DUERS .... Defense Utility Energy Reporting System
EISA .... Energy Independence and Security Act of 2007
EO .... Executive Order
EPA .... Environmental Protection Agency
EPAct .... Energy Policy Act of 2005
ESA .... Endangered Species Act
EUI .... Energy Use Intensity
F .... Fahrenheit
FEMP .... Federal Energy Management Program
GSWC .... Golden State Water Company
IMCOM .... Installation Management Command
IMP .... Integrated Management Practices
IWV .... Indian Wells Valley
KW .... Kilowatt
LCCA .... Life-Cycle Cost Analysis
LEED .... Leadership in Energy and Environmental Design
LID .... Low Impact Development
MCAGCC .... Marine Corps Air Ground Combat Center
MCIWEST .... Marine Corps Installations West
MCL .... Maximum Contaminant Level

MCLB	Marine Corps Logistics Base
MGD	Million Gallons per Day
MOU	Memorandum of Understanding
MW	Megawatt
MWA	Mojave Water Agency
NASA	National Atmospheric and Space Administration
NAVFAC	Naval Facilities Engineering Command
NAWS	Naval Air Weapons Station
NPDES	National Pollutant Discharge Elimination System
NTC	National Training Center
ORD	Office of Research and Development
ORISE	Oak Ridge Institute for Science and Education
PPA	Power Purchase Agreement
PPV	Public-Private Venture
PV	Photovoltaic
RDAT&E	Research, development, acquisition, testing and evaluation
RWQCB	Regional Water Quality Control Board
SDWA	Safe Drinking Water Act
SGMA	Sustainable Groundwater Management Act
SHC	Sustainable and Healthy Communities
SSWR	Safe and Sustainable Water Resources
StRAPS	Strategic Research Action Plans
SWRCB	State Water Resource Control Board
TDS	Total Dissolved Solids
UFC	Unified Facilities Criteria
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USGBC	U.S. Green Buildings Council
USGS	United States Geological Survey
USMC	United States Marine Corps
WhAEM	Wellhead Analytic Model
WWTP	Wastewater Treatment Plant

Executive Summary

According to the 2014 Department of Defense (DoD) Strategic Sustainability Performance Plan, in order to successfully execute its mission, DoD needs access to water, energy, land, and clean air for training and operating both now and into the future. Sustainability and resilience: DoD requires both for its energy, water resource, and waste management systems, particularly under climate change. In the arid southwest region of the United States, The interplay between the amount of water used to generate and transmit energy, and how much energy it takes to collect, clean, move, store, and dispose of water and waste poses unique challenges for the long-term sustainability of water resources for military installations. Extreme weather events and other factors have been and will affect water availability in the southwestern U.S. These events can also threaten and disrupt installation operations.

The U.S. Environmental Protection Agency's (EPA) Strategic Plan explains that the Agency will take appropriate action to "advance sustainability science, indicators, and tools" and "promote new ways to encourage technology-focused innovation that supports Agency priorities for sustainability" (EPA, 2014). However, identifying innovative and intuitive approaches that embody sustainability is a challenge, especially because the dependency and interconnections between water and energy, waste and energy, and even waste and water require that these resources be managed in an integrated fashion. The EPA's Office of Research and Development (EPA/ORD), through its various National Research Programs, seeks to provide data, science, tools, and approaches that address the complex interactions between water, energy, and waste at the local, regional, national, and global scales. These efforts aim to support water-energy-waste resources management decisions that can ensure the sustainability and resilience of installations and the vitality of the surrounding communities that are economically dependent on these installations.

In February 2012, EPA and DoD, through the Assistant Secretary of Defense for Energy, Installations, and Environment (ASD-EI&E), signed a MOU to "cooperate in research, development, and demonstration of technologies that can be used to achieve mutual goals." Now, through ORD's National Research Programs, EPA scientists and engineers are working with military partners to identify new and innovative technologies, methods, and approaches that foster installation sustainability and resiliency through integrated management of resources in the areas of water, energy, and solid waste. Given the unique challenges at installations and communities in the Mojave Desert of California, EPA/ORD proposed an initial scoping exercise based on stakeholder engagement for a set of federal installations in the Mojave to identify and evaluate critical resource management challenges at each installation, data needs and availability, and research needs to support potential innovative resource management options. The proposed federal participants included:

- Naval Air Weapons Station, China Lake;
- Edwards Air Force Base, Edwards;
- National Training Center, Fort Irwin;
- Marine Corps Air Ground Combat Center, Twentynine Palms; and
- the Marine Corps Logistics Base, Barstow.

Given these installations mostly rely on groundwater for their water needs, the stakeholder engagement and scoping exercise initially set out to focus on identifying and prioritizing critical water challenges and combinations of technology and potential water management options that could be supported by new scientific research and employed across the installations to help ensure the sustainability of their water resources. Based on initial conversations with the installations, the scope of the exercise was expanded to explore synergies or tradeoffs between the installations' water, energy, and waste needs in order to identify research, development, and demonstration opportunities to conserve water, recharge groundwater, reduce energy use, reduce solid waste landfill disposal and enhance resource recovery from both solid waste and waste water.

The overall goals of this stakeholder engagement and scoping exercise are to:

1) Identify challenges, themes, and strategies for enhancing the sustainability and resilience of Mojave installations, focusing on research to support solutions for integrated management of water, energy, and solid waste;
2) Identify potential research, development, and/or demonstration projects that would make a visible difference in meeting the installations' sustainability and resilience goals, while also meeting the research objectives of EPA/ORD's National Research Programs;
3) Identify common themes and approaches across all the installations and recommend a framework for regional cooperation/collaboration if appropriate;
4) Create a final regionally-themed synthesis document of the stakeholder engagement and scoping efforts.

This document serves the purpose for objective #4.

There are several findings and recommendations stemming from this stakeholder engagement and scoping exercise. They are summarized as follows:

A. Installations have already taken extraordinary measures to increase their water and energy efficiency and reduce water and energy intensity in response to both federal mandates, and the need to conserve resources. Most "low hanging fruit" has already been picked. Even with increased efficiencies and reduced demand, the water budget would still remain out of balance without addressing the supply side.
B. Installations face common challenges, especially with respect to the long-term sustainability of water resources. All five installations rely on groundwater and some exclusively. There are significant hurdles to cost-effectively maximize the potential for on-site renewable energy generation. Solid waste and waste water are resources yet to be fully realized. In particular, waste management should also be considered when planning for sustainable water management; when food is wasted, water is also wasted. It is possible to recover water from food waste that would otherwise be lost to landfill.
C. Common solutions for water, and at the water-energy and water-waste-energy nexuses could address these challenges. These include:
    a. Water:

    i. The majority of installations have the potential for capture and recharge of stormwater runoff. This practice, if determined feasible through new ORD led research, would reduce evaporative losses of water and increase recharge rates.
    ii. The installations have access to non-potable water resources that are not currently being used which include non-potable groundwater, stormwater runoff, domestic wastewater treated to secondary or tertiary standards, industrial wastewater, water used in open systems that could be converted to closed-loop recycling systems, condensate on equipment, and potentially other sources as well.
    iii. The water resource programs at all of the installations would benefit from installing additional water meters to track usage for various functions on the installations. Most of the installations have plans to do so over time.
  b. Water-Energy: the installations' energy needs could be reduced by evaluating the costs related to production and transport of excess potable water, for which the purposes of non-potable water could substitute.
  c. Water-Waste-Energy: The installations collect, process, and dispose of various forms of food waste and solid waste that could potentially be recycled, composted, or converted to water or fuel sources.

D. Several collaborative projects, to be led by EPA/ORD, are recommended:
  a. Fort Irwin NTC - Focused Recharge: Prioritizing Percolation of Treated Wastewater in an Arid Environment
  b. MCAGCC Twentynine Palms - Net Zero Waste
  c. MCLB Barstow - Centralized Storage and Distribution of Non-potable Water
  d. China Lake NAWS - Recharge Within Cantonment / Urban Areas
  e. Edwards AFB - Assess Energy and Water Resilience of Installation

E. The installations could benefit from a Net Zero and adaptive management approach to address their challenges. Net Zero, which represents "sustainability in action," quantifies environmental outcomes, meets environmental objectives of clean air and water and waste reduction or elimination to landfills, provides a framework for innovation, and manifests the time-dimension of sustainability: by achieving net zero, the long term viability of resources is not only maintained, but improved.

F. Given the shared resources and shared challenges among the installations, as well as the potential for similar solutions, there would clearly be a benefit to collaboration and coordination on a regional scale in the Mojave. It is recommended that this regional scale coordination be explored through the Desert Managers Group (DMG), which was established as a forum for government agencies operating in the Mojave Desert region to address and discuss issues of common concern. Additionally, depending on the number of projects that develop out of this effort, it could be useful to charter a project advisory group from the participating installations to enhance cooperation at a regional scale.

G. It is recommended to not only renew the MOUs with the Army and DoD, but also to develop a separate MOU with the Department of the Navy to serve as an umbrella for projects with MCAGCC Twentynine Palms, MCLB Barstow, and China Lake NAWS.

These projects, the MOUs to underpin them, and the regionally-coordinated efforts support integrated decision making at participating installations and operational efficiencies. These efficiencies will enable installations to more effectively and efficiently direct efforts and funds to increase their sustainability, develop an optimal portfolio for integrated water, energy, and waste management, and increase their overall resilience. The installations, in collaboration with EPA/ORD, can develop an adaptive energy-water-waste resource management portfolio consisting of technologies and behavioral changes that directly contribute to the long-term resilience of an installation, individually as well as the multi-service Mojave Range Complex. Chiefly, water management strategies or technologies deemed the most suitable for creating resilient desert-based installations will be transferable to non-military communities in the region and potentially across the U.S. This overall effort will promote resource conservation and management in the context of the federal agency mission. EPA/ORD will benefit from the opportunity to further apply and enhance its tools and models to sustainable water use challenges, integrating amongst water-energy, and waste recovery-water systems. All efforts will complement on-going research and will be consistent with the focus of ORD's research efforts on sustainable communities, systems thinking, environmental protection, and decision-support analyses.

1 Introduction

The Department of Defense (DoD) operates five unique and strategically important military installations in the Mojave Desert of California.

The U.S. Army's Fort Irwin National Training Center (NTC) is an essential component of the Army's (and DoD's) large-scale training program. Military units from all Services visit to train on this unique facility, including approximately ten brigade-sized exercises per year (NTC, 2015).

The Marine Corps Air Ground Combat Center (MCAGCC) at Twentynine Palms is a key training facility for the Marine Corps, supporting live-fire combined arms training, urban operations, and Joint/Coalition level integration training. Most of the live-fire combined arms training and Joint/Coalition Integration Training can be done at no other USMC installation (MCAGCC, 2015a).

The Marine Corps Logistics Base (MCLB) Barstow provides essential and unique logistics support for the Marine Corps, Army and other government organizations. The mission includes procurement, maintenance, storage, and issuance of supplies and equipment. The maintenance function includes rebuilding and repairing ground-combat and combat-support equipment for military operational units. MCLB Barstow provides logistics support to military installations from the U.S. West Coast to the Far East (MCLB, 2016b).

Edwards Air Force Base (AFB) possesses unique attributes and capabilities and a state-of-the-art facility for air and space flight experimentation and testing. Edwards is the test-bed for today's premiere aerospace technology programs including the Global Hawk, Hypersonic flight, and the F-35 Joint Strike Fighter (Edwards AFB, 2015).

Similar to Edwards AFB, the China Lake Naval Air Weapons Station (NAWS) is a key asset for the Navy. This largest Navy installation is critical for weapons system development and ground and air flight testing for the Department of the Navy. The scope includes operational test and evaluation of all air-to-ground weapons, air-to-air weapons, sensors, electronic warfare systems and mission software upgrades to aircraft and weapon systems (NAWS, 2016).

Each individual installation is vitally important to its Service and provides support to other Services and government organizations as well. The training and testing complex that is created by the proximity and extensive land and designated airspace (the R-2508 Special Use Airspace Complex) in this region provides a synergy that is unmatched within the US (Global Security, 2016). On the other hand, the average high temperatures and low precipitation, and seasonal extreme weather events of the Mojave Desert region present challenges for the resilience and sustainability of these installations, particularly as it relates to water resources. Adequate supplies of water are required for installations to maintain the capacity to conduct many live fire maneuvers, aviation operations, and other critical missions, and provide water for a range of uses including cooling buildings and equipment, domestic use, cleaning heavy duty vehicles, and fire-fighting activities. Installations that obtain their water from off-site sources may be at higher risk for potential disruptions in supplied water because they consume water procured from local utilities and compete with regional communities to use these water resources.

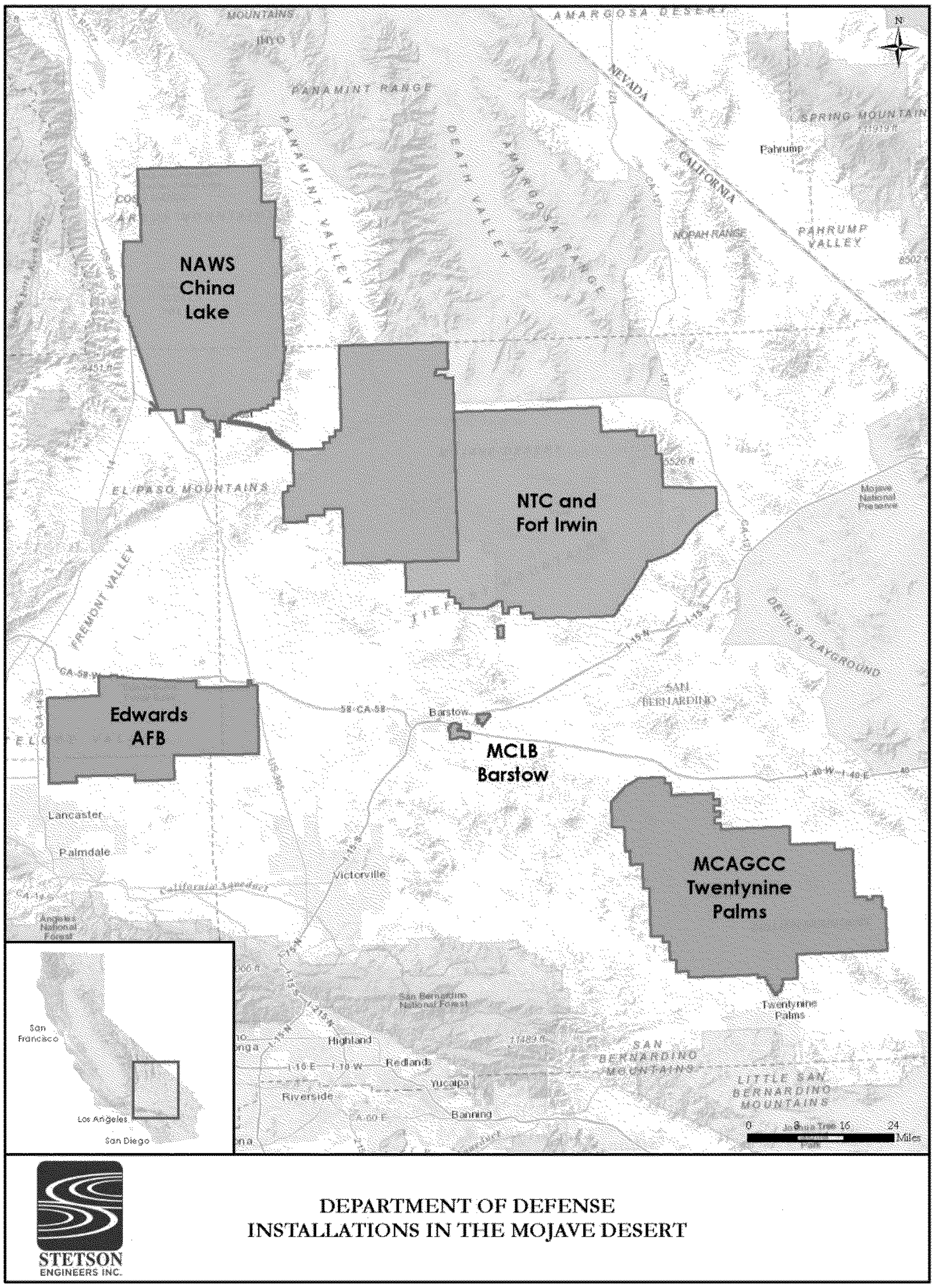

Figure 1. Regional Map of DoD Installations within the Mojave Desert

1.1 Installations at a Crossroads: Net Zero and Adaptive Management as Solutions

Disruptions in water, energy, or waste management services can threaten installation operations. The Mojave installations continue to operate with an adequate supply of resources to sustain mission requirements currently. However, much of the water supply is dependent on external sources from water service providers who face risks to their ability to deliver water supplies for the installations that purchase water. Likewise energy utilities are challenged at times in conveying and delivering electricity across the region. This supply uncertainty cannot be directly mitigated by the services, except to develop additional energy and water resources onsite. However there are limits on their ability to do so, as is discussed later in this report.

Sustainable energy-water resource management is critical to ensuring continuity of the military mission and the vitality of the surrounding communities that are economically dependent on these installations. Management of solid waste is also important because it requires energy and solid waste can be converted to energy and/or water. In addition, diverting resources from landfills preserves precious training, testing, and operating real estate. Resource sustainability needs to be incorporated into planning, decision-making, and day-to-day operations to ensure resiliency of the military installations (DoD, 2014), where resilience is "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

One framework that has proven successful in addressing these sustainability and resilience challenges is "Net Zero." Within the US Federal government, the US Army took a lead role in 2010 in adopting this concept when they announced a Net Zero initiative for installations with the moniker "Net Zero is a Force Multiplier." According to its vision for Net Zero, the Army is ". . . creating a culture that recognizes the value of sustainability measured not just in terms of financial benefits, but benefits to maintaining mission capability, quality of life, relationships with local communities, and the preservation of options for the Army's future."

As a 'Sustainability in Action' framework, Net Zero can also prove useful for installations in the Mojave.

The elements of Net Zero, adapted by EPA/ORD from the Army, are defined as follows:

> *Achieving Net Zero Energy means producing, from renewable resources, as much energy on site as is used, over the course of a year.*
>
> *Achieving Net Zero Water limits the consumption of freshwater resources and returns water back to the same watershed so not to deplete the groundwater and surface water resources of that region in quantity and quality over the course of a year.*

Achieving Net Zero Waste means reducing, reusing, and recovering waste streams, converting them to resource values with zero landfill over the course of a year.

Additionally, DoD also needs to build resilience into its systems (DoD, 2014). Energy and water resilience for installations "ensures mission sustainability in the face of uncertain and changing energy and water resource availability" (Thomas and Kerner, 2010). "This new focus will also ensure future planning addresses not just energy supplies, but actual mission performance for the widest range of circumstances" (NDIA, 2013).

Ensuring resilience requires a flexible management strategy that lends itself to complex and evolving systems. Given the ubiquitous role of energy and water resources and waste generation and management for installation operations, the impact of changes in those resources cannot be addressed by "snapshot" management approaches. An adaptive management approach is needed to assess the status of critical systems, determine their dependencies and vulnerabilities, hypothesize how changes can be addressed, develop metrics and targets to measure the effectiveness of steps taken, and adjust in a continued pursuit of building resilience into systems (Thomas and Kerner, 2010).

If pursuing system sustainability and resilience are the ends and adaptive management is the approach for achieving these ends, then what specific information, tools, and procedures are to be used as a means for achieving sustainability and resilience goals? Or stating this differently:

What information should be gathered and used to develop and assess successful tools for an adaptive management approach? Addressing this question is the focus of this report.

Making successful energy-water management decisions requires a framework of innovative data, tools, and procedures that address the complex interactions between water and energy via a structured process that accesses relevant information from local, regional, and national perspectives. Since energy and water are embedded in, required to manage, and can be extracted from solid waste, it too becomes a resource to manage within this Energy-Water-Waste Management Framework.

The installations, in collaboration with EPA/ORD, can develop decision support tools and scenario-based strategies that can be used to develop an adaptive energy-water-waste resource management portfolio consisting of technologies and behavioral changes that directly contribute to the long-term resilience of an installation, individually as well as the multi-service Mojave Range Complex. The dependency and interconnections between energy, water, and waste require that these resources be managed in a coordinated fashion. The shared resources and shared challenges among the installations, as well as the potential for similar solutions point to the benefits of collaboration and coordination on a regional scale. A major recommendation of this report is to explore this regional scale coordination through the Desert Managers Group (DMG), which was established as a forum for government agencies operating in the Mojave Desert region to address and discuss issues of common concern. Additionally, depending on the number of projects that develop out of this effort, it could be useful to charter a project advisory group from the participating installations to enhance cooperation at a regional scale.

1.2 Climate Challenges

Added to the challenges discussed above are those associated with extreme weather events that are projected to affect water and energy resources and demands. The Mojave Desert climate is hot and arid. Temperature and precipitation vary with elevation, but in summer daily maximum temperatures almost always exceed 90°F, and on average, daily maximum temperatures climb above 100°F from early June through late September. Annual rainfall averages less than 5 inches (CA DWR, 2004).

Research indicates that global climate change is likely to affect the military installations of the Mojave Desert over the next several decades (Garfin et al., 2013). Different climate model projections show varying degrees of temperature change, but all indicate that the region will warm. All also indicate variability in temperatures at short-term to multi-decade time scales due to natural weather and climate fluctuations. The average amount of warming is likely to be in the range of 4-5°F by the 2060's (Pierce et al., 2013a). There is likely to be less warming in the winter (~3-4°F) and more warming in summer (5-6°F). Extreme hot temperatures are projected to increase more than average temperatures. There is a great deal of uncertainty, however, regarding the rate and timing of warming due to unpredictable natural variation, uncertainty in climate physics, differences between model assumptions and human behavioral responses and policy choices, and other factors (Cayan et al., 2008; Cayan et al., 2013).

Warmer conditions increase evaporation from the surface and transpiration from plants. Irrigated land cover tends to increase water loss with rising temperature (greater amounts of water are lost via leaf stomata). Non-irrigated plants will react to overly hot conditions by shutting stomata, leading to reduced water loss but also to wilting. Warmer conditions also lead to increased use of evaporative coolers and towers, and thus lead to greater human water and energy use and waste generation. An increased need for non-evaporative cooling, as well as increased pumping and treatment of water will lead to increased energy consumption as well.

Research regarding potential changes in precipitation is less clear. Projections suggest little change in the average annual total precipitation. Spring and autumn declines in precipitation may be balanced by increases in summer monsoonal precipitation (Pierce et al., 2013a). Research points to an overall decrease in the number of wet days per year and an increase in the quantity of precipitation on those wet days (Pierce et al., 2013b; Polade et al., 2014).

On average, climate model projections indicate continued strong variability of precipitation from year to year and decade to decade (Cayan et al., 2008; Pierce et al., 2013a). Wetter extremes but longer dry spells would produce more volatility from one year to the next (Berg and Hall, 2015) and increased occurrence of drought (Cook et al., 2015). The intensity of the droughts may increase in association with the warmer temperatures (Cayan et al., 2010).

Precipitation during warm summer conditions is more likely to be lost to evaporation or evapotranspiration, rather than infiltrating into the soil and recharging the aquifer. Likewise, precipitation during more intense events is likely to recharge less groundwater than less intense precipitation events that soak deeper into the soil.

For those installations directly or indirectly dependent upon imported State Water Project (SWP) water, it is important to note that the long term supply of imported water could decrease if climatic factors in the Sierra Nevada become unfavorable. Although present model projections do not indicate significant changes in overall precipitation in the Sierra Nevada (Pierce et al., 2013a), there could be changes in the water supply due to reductions in snowpack and increases in winter flood flows (Dettinger et al., 2015; Cayan et al., 2016), which would likely become more difficult to manage than the current spring-summer snowmelt runoff. And it should be noted that SWP resources have proven to be sharply constrained in times of drought. For instance, the 2015 water allocation to the SWP was only 30% of normal due to drought conditions in the state.

These climate change considerations, the uncertainty regarding the extent and direction of change, and the potential impacts due to the changes demand a robust planning framework to guide the military installations forward as they adapt energy, water, and waste management programs to fit the evolving environment.

1.2.1 Regulatory and Legal Environment

Factors that influence effective management of water resources include the legal framework for surface and groundwater rights, natural hydrological processes, human and environmental water demands (including support for threatened/endangered species habitat), climate change, demographic trends, water use and conservation practices, water pricing/markets, state/federal water quality regulations (including those for stormwater management and water reuse), and energy availability for pumping, conveyance, treatment, and distribution of water. This is a complex and evolving policy landscape for military installations and their regional headquarters to navigate.

Factors that influence the effective management of energy resources include availability of renewable sources of generation, diversity of suppliers, markets, availability of third party financing, flexible contract tools (e.g. power purchase agreements (PPA), enhanced use leases, and utility privatization), available water for cooling and hydroelectric generation, and a regulatory framework that has developed in a manner tailored to the requirements of civilian rather than military utility providers. Again, a complex and evolving policy landscape.

These laws, regulations, directives, and other mandates are “drivers” for military installations’ policy choices. These drivers include the following, which are discussed in Appendix A:

- Safe Drinking Water Act (SDWA)
- Clean Water Act (CWA)
- Energy Policy Act (EPAct)
- Resource Conservation and Recovery Act (RCRA)
- Energy Independence and Security Act (EISA)
- Executive Orders (EO) 13423, 13514, and 13693
- Endangered Species Act (ESA)

- Water Rights Regulations and Case Law
- State Laws and Regulations such as California's Sustainable Groundwater Management Act (SGMA), California's Mandatory Commercial Organics Recycling legislation, and other regulations adopted by the California State Water Resource Control Board (SWRCB).
- DoD Directives
- Service Directives

In addition to the physical challenges and legal, regulatory, and related mandates that act as drivers for local decision making, there are other factors that installation managers must consider, including:

- Perceived need for energy and water security
- Spending limitations set by budgets
- Achievement of Strategic Plan goals and objectives
- Demand for utility services by customers
- Workforce limitations
- Health and safety concerns

These drivers influence the choices and priorities of installation managers as they develop and implement plans, programs, and policies to address energy, water, and waste challenges. While most of the external drivers are shared across the Mojave, the installation-specific differences can lead to different approaches being adopted to meet different challenges. However, several common themes have emerged, with the potential for similarly adapted solutions, particularly focused on approaches for groundwater recharge.

1.3 EPA – DoD Collaboration

In 2011, the U.S. Environmental Protection Agency's Office of Research and Development (EPA/ORD) signed a memorandum of understanding (MOU) with the US Army to support the Army's Net Zero Initiative. Under the MOU, EPA/ORD scientists are working with military installations to demonstrate and assess innovative Net Zero technologies and approaches that will help the installations achieve their net zero goals while advancing the state of science.

In 2012, EPA ORD and DoD, through the Assistant Secretary of Defense for Energy, Installations, and Environment (ASD-EI&E), signed an MOU to "cooperate in research, development, and demonstration of technologies that can be used to achieve mutual goals," thereby extending this collaboration to the other Services. Through ORD's national research programs, EPA scientists and engineers are working with military partners to identify new and innovative technologies, methods, and approaches that foster installation sustainability and resiliency through integrated management of resources in the areas of water, energy, and solid waste.

In 2016 DoD issued Directive 4715.21 "Climate Change Adaptation and Resilience" which establishes policy and assigns responsibilities to provide DoD with resources necessary to assess and manage risks associated with the impacts of climate change. The document directs the Assistant Secretary of Defense for Energy, Installations, and Environment (ASD(EI&E)) to: 1) collaborate with other federal agencies on climate change-related research to produce "actionable science"; and, 2) support efforts to identify, develop, and demonstrate technologies, engineering standards, tools, and approaches that enable climate change adaptation and resilience.

1.4 Study Objective and Approach

Understanding the resource management challenges faced by military installations in the Mojave Desert, and understanding the implications of the climate change research, DoD managers and EPA/ORD are focused on developing a sustainability pathway that navigates from where the installations currently are to where they need to be in 30-40 years in terms of resilient energy, water, and waste management systems.

EPA ORD representatives met with the Desert Managers Group during mid-2015 to ascertain what military installation managers from the deserts in southern California were most concerned about. Water sustainability, finite groundwater supplies, and aquifer recharge were at the top of their list, and that knowledge focuses the water resource aspects of this initiative.

1.4.1 Objective

EPA ORD seeks to identify critical water, energy, and waste challenges and themes common among Mojave installations; identify synergies and tradeoffs based on installations' needs; introduce new solutions that build on progress already made by installations; and focus on demonstrating technologies and strategies that can be implemented to ensure sustainability and resiliency. These datasets, tools, and procedures can ultimately be employed within an energy-water-waste management framework as discussed above.

Working with the military to address these water and energy challenges and coordinating with the military regarding successful strategies employed on installations provide a means for leveraging this research for the benefit of communities across the region while also providing specific benefits to DoD in accordance with the MOUs discussed above. Therefore, EPA ORD is assisting the participating DoD installations in evaluating progress, opportunities, and challenges relevant to their individual and holistic water and energy goals by using EPA risk management and decision support tools.

1.4.2 Approach:

The EPA ORD approach is to:

- Coordinate with DoD installation stakeholders in the Mojave Desert

- Perform site visits to interview stakeholders and increase understanding of the installation-specific and regionally common energy, water resource, and waste management challenges
- Identify information, datasets where available, tools, and procedures that can be employed and refined over time to build energy-water-waste resilience on military installations in the Mojave Desert

This report covers these three bullets. A potential next phase for this initiative is to:

- Develop a framework for managing this energy, water and waste management portfolio using EPA risk management and decision support tools.

This analysis explores how strategic options and conceptual approaches to resource resilience challenges may affect overall installation and regional sustainability and resilience, where resilience is defined as “the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions” (Executive Order 13693).

In addition to considering water and energy challenges directly, this analysis also includes a focus on the water-energy nexus: the relationship between the amount of water used to generate and transmit energy, and how much energy it takes to collect, clean, move, store, and dispose of water. Key focus areas include water reuse and wastewater treatment technologies, behavioral change, and asset management at the installation and regional scales. It should be noted that this proposed research does not present a comprehensive examination of the various conservation and efficiency programs for water, energy, and waste that the installations have already adopted over decades of managing theses resources. Rather, this research is focused on those particular aspects of these programs that may benefit from new and innovative EPA/ORD collaborative research.

This research can be leveraged across the arid Southwest region among DoD installations and civilian communities, municipalities, water and energy utilities, and developers, assisting both regional and local decision making to promote resource conservation, sustainability, and resilience. This effort aligns well with current ORD research priorities for sustainable communities, systems thinking, environmental protection, and decision-support analyses, providing an opportunity to integrate EPA expertise, tools, and modeling with water-energy expertise from other federal partners (including the DoE Water-Energy Tech Team, DoD Installations and Environment Water Needs Assessment Tool, USACE Sustainable Installations Regional Resource Assessment framework, and Sandia National Laboratories Water Security Program Energy and Water Data Portal).

This research also aligns well with the EPA Safe and Sustainable Water Resources Action Plans (StRAPs), relevant elements of which are contained in Appendix C.

2 Study Findings

The EPA/ORD assembled a team to perform site visits and interviews with military installation stakeholders at Fort Irwin NTC, MCAGCC Twentynine Palms, and Edwards AFB during 2015 and MCLB Barstow and China Lake NAWS during 2016. Appendix B provides supplementary information for each installation visit.

The purpose of these visits was to conduct an initial on-site meeting between EPA/ORD and installation personnel to:

- Discuss the installations' current energy, water, and waste programs and challenges;
- Identify specific needs and potential demonstration projects in collaboration with EPA that can assist the installations as they move toward becoming more sustainable; and
- Generate new scientific understanding that can be broadly applicable.

The EPA ORD team discovered several recurring challenges that the Mojave installations face. The commonality of these challenges across the region may represent an opportunity for addressing them at the regional scale. It may also present an opportunity for both Net Zero approaches that can quantify progress towards sustainability goals, and an adaptive management approach wherein information, datasets, tools, and technology can be employed and refined over time to build energy-water-waste resilience on military installations.

2.1 Regional Challenges

2.1.1 Energy

While the potential for capitalizing on solar energy is high, the installations reported on the administrative and regulatory limitations that restrict development of on-site renewable energy above certain base-load caps. The military installations have interests broadly in achieving renewable energy goals, however unique challenges in the region regarding interconnection challenge their ability to achieve these goals. California's Electric "Rule 21" establishes technical requirements and procedural criteria for connecting electricity generating equipment to the regional utility distribution systems. Installation energy managers state that these requirements have the effect of limiting the amount of on-site energy generation that each installation can cost-effectively develop. For instance, installing energy generation facilities in excess of 1 MW requires an installation to add expensive real-time telemetry equipment. Standby and Departing Load charges are also expensive, offsetting savings to be made with demand reduction and eroding economic incentives for installing the facilities in the first place. California Senate Bill 83 provides some measure of relief in this regard, however development of renewable energy on the installations remains sub-optimized. Solar and wind energy facilities on some installations are operating below capacity, and in some cases they are not even connected and turned on. This level of systemic inefficiency is disconcerting to installation managers as it wastes Federal resources. Recent policy changes may remove some of these impediments to renewable energy interconnection and spur more renewable energy development on the installations in the near future.

2.1.2 Water

The hot, arid desert environment presents its own challenges for water resources. Little precipitation, high evapotranspiration rates, and low aquifer recharge rates combine to make water management the key issue for the long term sustainability of these installations. Much of the precipitation that does occur fails to recharge aquifers, but instead evaporates from playas and other surface waters.

The geographic isolation of most of these installations limits availability of imported water. Declining groundwater levels in sole-source aquifers are an existential threat, the timeline of which varies from basin to basin according to the size of the basin, recharge rates, and rate of groundwater withdrawal. Adding complexity to this situation, many of the basins are shared with neighboring civilian communities, with management of such basins often done in an uncoordinated fashion. Shared basin management has not been the norm. This is likely to change over time with the establishment of Groundwater Sustainability Agencies (GSA) under SGMA.

An additional challenge is that most water uses at the installations are not metered, so data are lacking for specific water uses, including trends and responses to various policy interventions.

2.1.3 Waste

There appear to be fewer challenges with solid waste management. Although these large installations have ample acreage for waste disposal, there are costs associated with collecting, transporting, and managing landfills. In addition, there are federal, state, and DOD requirements for solid waste diversion. There are lost opportunities, however, for source reduction, reuse, and resource recovery in making use of waste resources to produce energy or water. Waste food and other solid waste contains water and energy potential that are imported to the system but are uncaptured and unused in most cases.

2.2 Common Solutions

This section presents solutions that are common to the five installations visited.

2.2.1 Energy

Installations have already taken measures to increase their energy efficiency. While DoD is supportive of efforts to develop on-site renewable energy at its installations, recent challenges with uncertain costs associated with interconnecting to the grid have spurred region-wide challenges associated with developing cost-effective on-site renewable energy projects at installations in the Mojave (DoN, 2012). One potential common solution to reduce installation energy needs is to evaluate the costs related to production and transport of excess potable water, for which the purposes of non-potable water could substitute.

2.2.2 Water

2.2.2.1 Stormwater Capture and Recharge

The majority of installations have the potential for capture and recharge of stormwater runoff. This practice, if feasible, would reduce evaporative losses of water and increase recharge rates. This practice could be performed within cantonment areas using existing stormwater conveyance channels and retention ponds, or outside of cantonment areas.

In order to determine feasibility, potential locations for injection wells would need to be identified and soil cores taken to ensure that there are no impediments to the stormwater reaching and recharging the Basin, and that the water is of sufficient water quality (and remains so as it percolates through the subsurface into the aquifer below) to be useful in the future. Treatment strategies may be required. The research will also determine at which ground depth the evaporation zone is surpassed and gravity takes over to pull water down into the aquifer.

2.2.2.2 Maximize Use of Non-Potable Water Resources

Installations have already taken measures to reduce demand for potable water and increase overall water efficiency. In varying degrees, the installations have access to non-potable water resources that are not currently being used. These non-potable waters include non-potable groundwater, stormwater runoff, domestic wastewater treated to secondary or tertiary standards, industrial wastewater, water used in open systems that could be converted to closed-loop recycling systems, condensate on equipment, and potentially other sources as well. Making use of these non-potable waters requires development of alternate water treatment, storage, and distribution systems which can be very expensive. However substitution of non-potable water for potable water can extend finite and diminishing potable groundwater resources – a key goal for most basins.

To determine the feasibility of such practices, studies would need to examine the availability (both quantity and timing), water quality, production costs, and treatment requirements and costs of the water sources, as well as the appropriate uses for such water and whether such use could substitute for current potable water application. Projects would entail a cost-benefit analysis of continuing to use potable groundwater (and recycled water in some instances) for current uses versus development of a system that also makes use of various types of non-potable water. The strategies examined might include integrated systems and decoupled stand-alone applications for specific uses, as well as rooftop stormwater capture and use, stormwater runoff capture and use, indirect potable reuse of recycled water, and other uses.

2.2.2.3 Additional Water Metering

The water resource programs at all of the installations would benefit from installing additional water meters to track usage for various functions on the installations. Most of the installations have plans to do so over time.

2.2.3 Waste

The installations collect, process, and dispose of various forms of food waste and solid waste that could potential be donated or reused, recycled, composted, or converted to water or fuel sources. There are also opportunities for waste reduction as well.

2.3 Best Practices

The following best practices were observed during the site visits to the five installations.

2.3.1 Energy

MCAGCC uses a 1 MW battery system to store electricity generated onsite. Given the limitations on cost-effectively developing local renewable energy, such onsite storage represents a key capability to enable energy security. Also, a 10 MW micro-grid system has been developed at MCAGCC, the largest in DoD (MCAGCC, 2015a).

China Lake has achieved a noteworthy onsite energy generation rate of 33%.

2.3.2 Water

Fort Irwin recently completed construction of an electro-dialysis advanced water treatment plant to treat groundwater at an extraordinary efficiency of 99.6%. This plant will enable the Fort to produce excellent quality potable water (reducing arsenic and fluoride levels to within Maximum Contaminant Levels [MCLs]). The plant is new, but appears promising as an example of the efficiency levels attainable as the installation pursues use of non-potable groundwater and preservation of limited potable water resources.

Edwards AFB has achieved a remarkable 70% reduction in water use intensity since 2007. MCAGCC has achieved a 56% reduction and China Lake a ~50% reduction since 2007, as well.

China Lake has reduced irrigated landscape by ~90% during the last 15 years.

China Lake has been participating in the collaborative groundwater management of the Indian Wells Valley Groundwater Basin and is a non-voting member of the new Groundwater Sustainability Agency being established for the basin. This level of collaboration within a basin management initiative goes beyond what most installations do and appears to be a promising development in cooperative planning to ensure sustainability of this shared, sole-source aquifer.

2.3.3 Waste

MCAGCC has achieved a 42% solid waste diversion rate through weekly collection and processing of recyclables from 1,720 family housing units and more than 300 offices. The installation is exploring additional measures to attain an even higher rate of diversion.

Fort Irwin NTC bails solid waste to facilitate mining of this resource from its landfill for use in a new waste pyrolysis plant.

3 Summaries of Site Visits to DoD Installations in the Mojave Desert

This section presents information gathered during these site visits and subsequent coordination with the installations.

3.1 National Training Center, Fort Irwin

Fort Irwin NTC is located in northern San Bernardino County, 37 miles northeast of Barstow, in the Calico Mountains (see Figure 2). The average elevation is 2,454 feet.

In 1940, President Franklin D. Roosevelt established the Mojave Anti-Aircraft Range, a military reservation of approximately 1,000 square miles in the area of the present Fort Irwin. In 1942, the Mojave Anti-Aircraft Range was renamed Camp Irwin, in honor of Major General George LeRoy Irwin. Camp Irwin was deactivated after World War II and then reactivated to serve as the Armored Combat Training Area for combat units during the Korean War. The post was designated a permanent installation in 1961 and renamed Fort Irwin. In 1979, Fort Irwin was selected as the site for the National Training Center due to its large area for maneuver and ranges, an uncluttered electromagnetic spectrum, airspace restricted to military use, and its isolation from densely populated areas (MilitaryBases.com, 2016).

Fort Irwin is a major training area for the DoD. It is part of the US Army Forces Command. Military units from all Services visit to train on this unique facility. Approximately ten brigade-sized units visit per year. The 11th Armored Cavalry Regiment, the "Blackhorse Cavalry," is stationed at the base to provide an opposing force to visiting units on a training rotation at Fort Irwin (NTC, 2015). The 2010 United States census reported Fort Irwin's population as 8,845. Managers estimate a daytime population of approximately 16,000. During a large training exercise, the base population can rise to 25,000 – 30,000 temporarily (NTC, 2015).

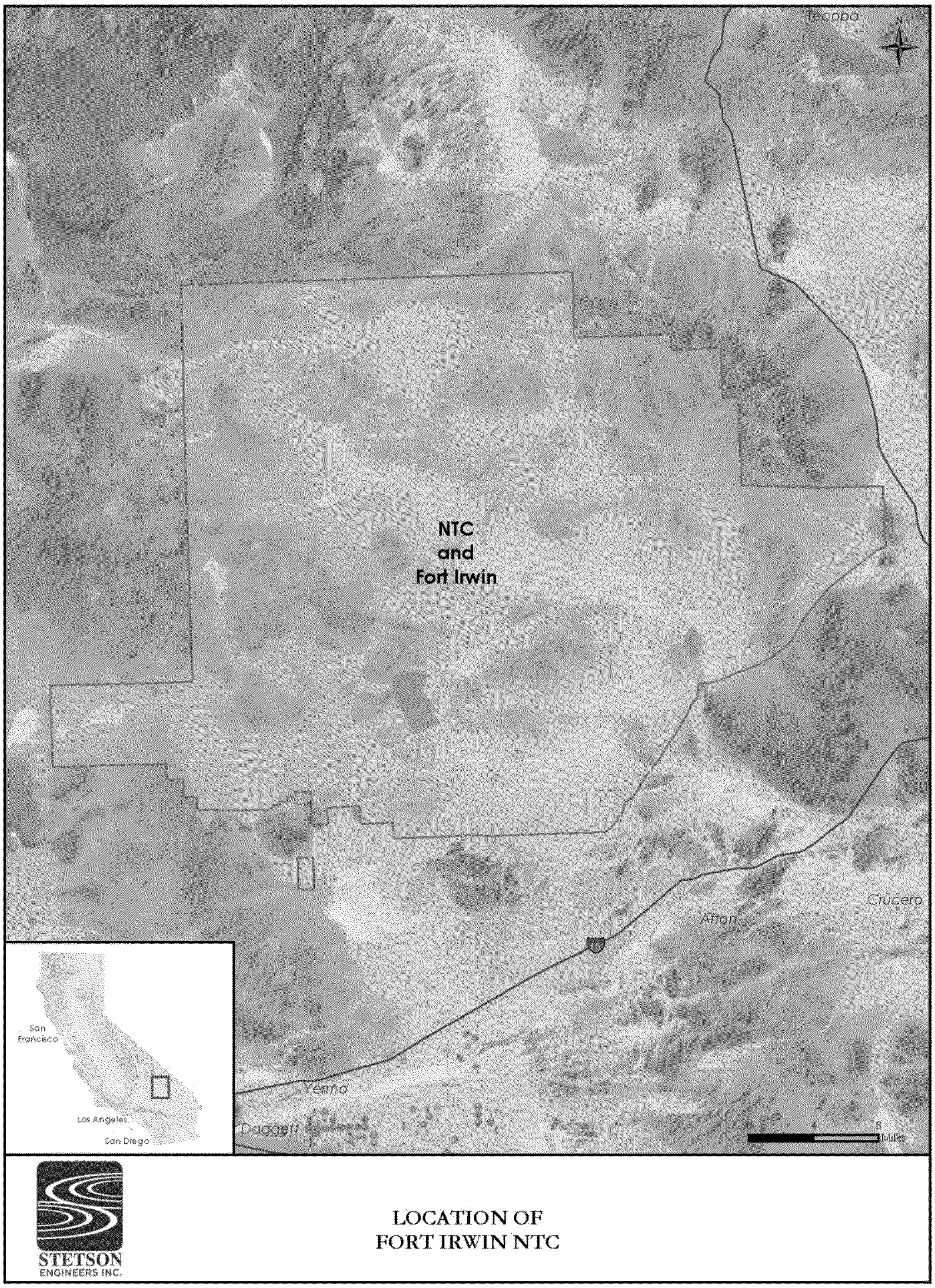

Figure 2. Fort Irwin National Training Center

3.1.1 Fort Irwin Challenges

The existing and long-term mission is dependent on an adequate and reliable source of drinking water. Located in an arid and remote location, Fort Irwin's water supplies are limited and diminishing. Surface water is ephemeral and insufficient as a source of direct supply. The installation has access to three groundwater basins for producing water: the Irwin Basin, Bicycle Lake Basin, and Langford Lake Basin. Additionally, there are two other basins of potential value: Coyote Lake Basin, for which the Fort has limited water rights, and Superior Lake Basin, for which the Fort has no water rights at this time. The Fort has been working with the US Geological Survey (USGS) since 1994 on basin studies and hydrologic modeling, and Fort Irwin Public Works managers estimate that they have a total of 50-70 years of available water remaining within the three groundwater basins currently in use. These water supply constraints drive most water management decisions on the Fort. Water conservation and efficiency measures have been aggressively employed, and the Fort has gone from using 960 million gallons/year in 2003 to using 703 million gallons in 2015 (a 27% reduction) (NTC, 2015).

Low water quality necessitated construction of a unique, electro-dialysis advanced water treatment plant at a cost of $100 million. This project was nearly completed at the time of the site visit. It will produce 3 MGD (6 MGD peak) of treated water at an extraordinary efficiency of 99.6%. This project will enable the Fort to produce excellent quality potable water (reducing arsenic and fluoride levels to within MCLs). Upon completion, the Fort plans to discontinue use of the current dual water system that supplies potable water and non-potable water to users on the installation (NTC, 2015).

Tracking water usage is difficult on Fort Irwin. Only about 10% of water use is metered using the approximately 200-250 water meters currently in place. Bulk metering is employed to monitor water use in Family Housing, and landscape irrigation is metered. Lacking sufficient metering, it is difficult for water resource managers to monitor potential leaks, obtain feedback on the effectiveness of water conservation initiatives and education and outreach campaigns, and manage water resources in general (NTC, 2015).

When it rains, the rate and volume of precipitation is often significant, resulting in dominant overland flow through washes outside of the developed area, and damaging uncontrolled flooding in the permanent cantonment area. Twice during the last decade severe storms have caused extensive flooding. Flood water conveyance and infrastructure protection is ineffectual. In some locations utility lines are buried too close to stormwater channels and are damaged by eroding flood events. In addition, many isolated stormwater conveyance projects have been designed and installed over the years with inadequate planning for continuity with stormwater conveyances on adjacent parcels. Insufficient thought had been devoted within project design and construction for the ultimate fate of stormwater once it departs a specific project site (NTC, 2015).

While water is extremely valuable in the Mojave, Fort Irwin does waste some water to evaporation that could otherwise be placed into use. Some recycled water is used for landscape irrigation, however approximately 60% of the treated wastewater is send to wastewater recharge ponds. A large percentage of this water is lost to evaporation and evapo-transpiration, while water that infiltrates actually recharges a high saline aquifer (~5000 mg/L TDS) that is not used for sourcing potable water. In the winter when irrigation demand is very low, almost all the water is sent to the recharge ponds. This recharge operation could be refined as recommended below to provide a higher benefit to the Fort and extend the useful life of the aquifers (NTC, 2015).

Water Resource managers on Fort Irwin seek a method for calculating the realistic value of existing groundwater and projects that preserve groundwater and the useful life of the aquifers. Having a better method for groundwater valuation (and therefore valuation of water conservation and efficiency projects) may enable planners to better justify water-related infrastructure projects, calculate ROI and payback periods, provide realistic discounting, and plan for water resource management into the future.

Fort Irwin has several alternative energy projects that diversify the energy portfolio including a Fresnel lens concentrating photo-voltaic (PV) farm (1 MW) (see Figure 3); a PV private purchase agreement project (15 MW); solar carports (750KW); PV at the new hospital (2.1 MW); a fuel cell demonstration project (65 KW); and a waste pyrolysis plant (nearing completion) (1.1 MW). The latter will produce energy from locally generated waste. The Fort has the potential to produce more energy locally, however interconnect limitation clauses within commercial utility agreements limit the Fort's ability to develop local energy production beyond the installation's baseload; this limitation is exacerbated because baseload is defined by the lowest-usage period (night) (NTC, 2015).

Figure 3. Concentrating photovoltaic farm at Fort Irwin.

3.1.2 Potential Solutions

During the site visit and in subsequent conversations a number of potential solutions to the Fort's water, energy, and waste challenges were discussed. The following sections provide an overview of the Fort's planned and ongoing initiatives as well as those that may be appropriate for an EPA/ORD led effort.

3.1.2.1 Fort Irwin Planned or Ongoing Initiatives

3.1.2.1.1 Stormwater Management Master Plan

The inadequate size and disconnected nature of the stormwater conveyance system is being studied. A draft stormwater management master plan has been developed to aid in planning. Utility line realignment is planned for some locations to reduce risk of flood damage.

3.1.2.1.2 Mountain-front Stormwater Capture and Infiltration

The Fort is studying the feasibility of constructing mountain-front stormwater capture and infiltration structures. This concept, if feasible, may yield multiple benefits for the Fort including aquifer recharge and stormwater management. The facilities would detain ephemeral storm-related surface flows and promote recharge of the aquifers on the fringe where groundwater quality is high, sediment characteristics support preservation of water quality throughout the infiltration process, and surface flows can be effectively subtracted from down-gradient stormwater management (and flooding) challenges.

3.1.2.1.3 Water Metering

Two water metering projects are programmed for the future in order to increase capabilities to track water usage and better manage infrastructure maintenance and water efficiency programs.

3.1.2.1.4 Groundwater Studies

The Fort continues to work with USGS to explore the feasibility of using additional groundwater basins as potential water sources.

3.1.2.1.5 Landfill Mining

The Fort bails its trash for placement in its landfill and plans to obtain a permit to mine this landfill as a feedstock for the waste-pyrolysis plant.

3.1.2.2 Potential EPA/ORD – led Initiatives

3.1.2.2.1 Focused Recharge: Prioritizing Percolation of Treated Wastewater in an Arid Environment

Fort Irwin has a seasonal excess of recycled water that could be recharged to groundwater which sources the Fort's water needs. The project would direct Fort Irwin's treated wastewater to infiltration structures within a stormwater conveyance channel where it can infiltrate down to recharge the aquifer below. The research will also determine at which ground depth the evaporation zone is surpassed and gravity takes over to pull water down into the aquifer. This project is discussed further in Appendix D.

3.1.2.2.2 Mini-model for Granite Canyon Neighborhood

This project would test EPA green infrastructure modeling tools using empirical data from the arid Southwest region. Using these models would allow managers to see what can be done, in regards to low impact development (LID) stormwater management, to prevent the flooding the neighborhood currently faces. This will build on recent work done by the U.S. Army Corps of Engineers on modeling stormwater conveyance up-gradient of the development.

3.1.2.2.3 Wellhead Model

EPA's Wellhead Analytic Model (WhAEM) is a groundwater flow model for use in wellhead protection. This model could be applied to define capture zones and protect wells at Fort Irwin.

3.1.2.2.4 Incorporate LID into Master Plan

The EPA could develop recommendations for how LID (or "Green Infrastructure") measures can be incorporated into the Fort Irwin area development master plans that guide development of the cantonment area (photo at Figure 4).

3.1.2.2.5 Opportunity Cost of Water Model

The EPA could develop a model to derive the opportunity cost associated with using finite and diminishing water resources today and running out of water in the future. Appropriately valuing local groundwater in situ (and not just the infrastructure related to its development and production) is necessary for comparing and justifying water infrastructure and conservation projects. Having a cost associated with water conservation will arm Fort Irwin managers with real data to make the case for investing in water conservation and sustainable water management.

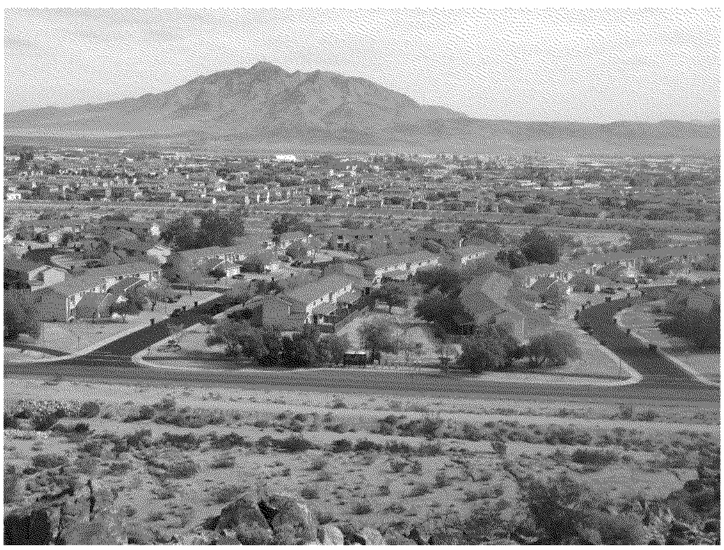

Figure 4. Cantonment Area on Fort Irwin.

3.2 Marine Corps Air Ground Combat Center, Twentynine Palms

MCAGCC is located approximately 50 miles northeast of Palm Springs (Figure 5). MCAGCC encompasses about 600,000 acres, with surface elevations ranging from approximately 600 feet to 4,700 feet above sea level. The Mainside Area and Camp Wilson are located at approximately 2,000 feet. MCAGCC is a key training facility for the Marine Corps, supporting live-fire combined arms training, urban operations, and Joint/Coalition level integration training. The mission of the installation is to promote operational forces readiness as well as to provide the facilities, services, and support responsive to the needs of resident organizations, Marines, Sailors, and their families (Stetson, 2014; MCAGCC, 2015a).

The installation hosts a number of tenant operational and training commands. These military units require reliable power and water utilities to support a variety of military training exercises and maneuvers. In addition, MCAGCC performs many activities associated with a typical civilian community including day care centers, elementary schools, college and university extensions, retail stores, restaurants, fire stations, military police, and maintenance facilities, which are similarly dependent on power and water utilities (Stetson, 2012 and 2014; MCAGCC, 2015a).

The installation has operated continuously since its establishment in 1953 supporting the training program for ground and air fire support in a live-fire, desert training environment utilizing the entire Marine Corps weapon inventory and nearly all munitions types. Support has also expanded as a response to military operations in the Middle East. Approximately 35,000–50,000 DoD military personnel train annually during Mojave Viper, Combined Arms Exercises (CAX), and other exercises at the installation. The population for the installation in 2015 was 21,936 (MCAGCC, 2015a and 2015c).

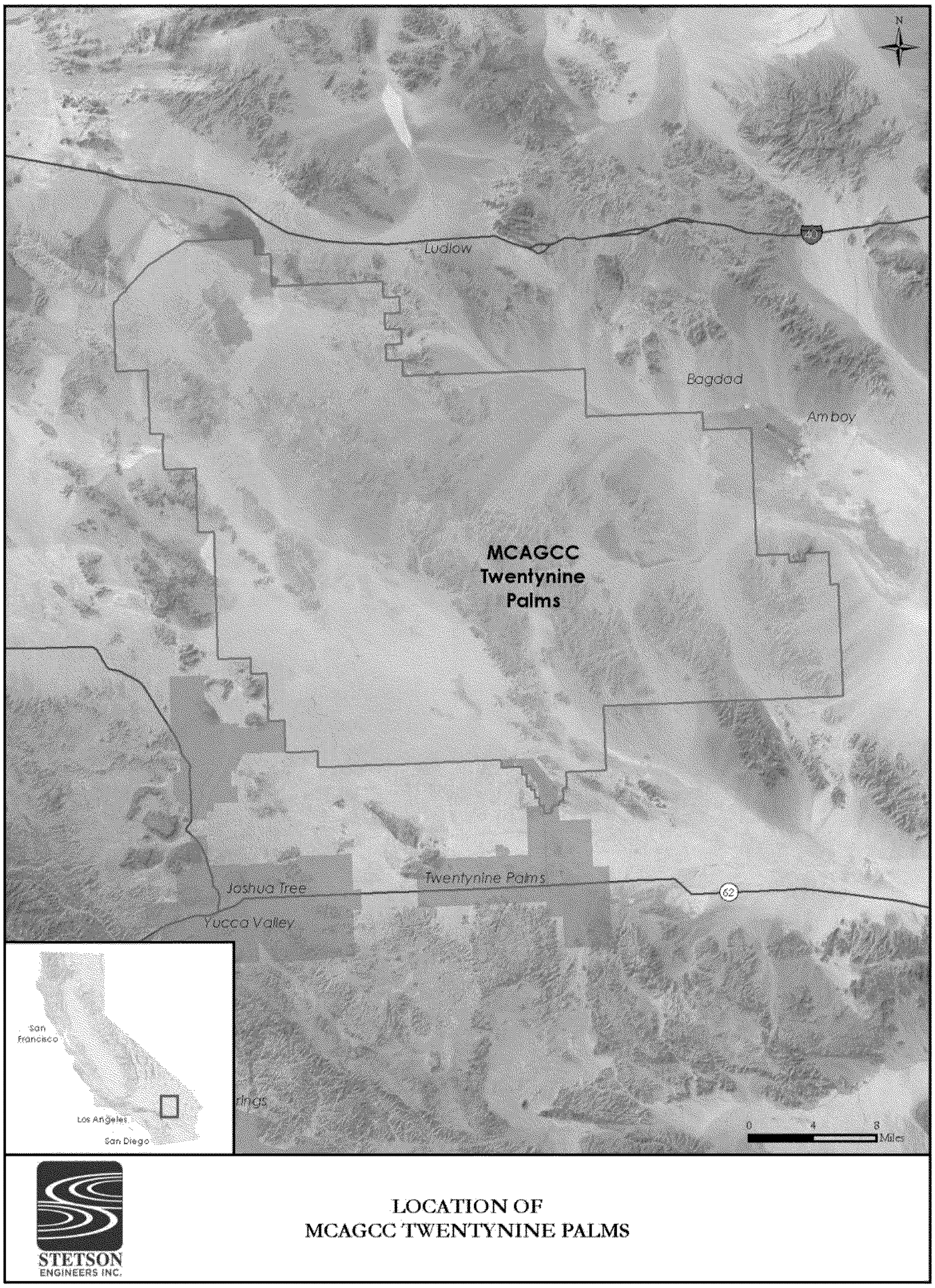

Figure 5. Location of MCAGCC.

3.2.1 MCAGCC Challenges

The existing and long-term mission of the installation is dependent on an adequate and reliable source of drinking water. Located in an arid and remote location, MCAGCC's water supply options are limited. When the land for MCAGCC was purchased from San Bernardino County in 1952, a principal criterion for site selection was the reliability of a local groundwater source. Development, maintenance, and protection of water resources remain integral functions more than 60 years later. Although MCAGCC has historically depended upon its own aquifers to meet its water demand, this self-reliance could be threatened over time as the limited groundwater source is drawn down. Water demand may increase as mission requirements and population change, new military units are moved to MCAGCC through the Base Realignment and Closure (BRAC) process, or tactics and weapons systems evolve, necessitating a higher operating tempo at the Combat Center (Stetson, 2012).

Water demand at MCAGCC is driven by four primary categories of use, including domestic, military, commercial/industrial, and irrigation. Key domestic uses include family housing, bachelor housing, and offices as well as the child development center, gymnasiums and swimming pools. Military uses include support for major field training exercises, mess halls, the naval hospital and clubs. Commercial/Industrial uses are dominated by cooling units and also include other uses such as vehicle washing, boilers and hydrant testing. Irrigation uses include landscaping, parade grounds, ball fields, playgrounds, and the golf course. These uses are primarily supplied by potable water sources with the exception of the golf course, some construction activities, and make-up water for wash racks. The golf course relies on a combination of non-potable and recycled water while the construction activities and make-up water for wash racks rely on non-potable water exclusively (Stetson, 2012).

Surface flows and recharge of groundwater are limited by the regional climate. Annual precipitation averages about 4-8 inches across the region with higher amounts in the mountainous areas and lower levels on the desert floor. Potential evapotranspiration rates in the region are also high, averaging about 66.5 in. per year, thus most of the precipitation is lost through evapotranspiration (Stetson, 2014).

Streamflow is ephemeral and is generally limited to high-intensity rainfall events. Infiltration from streamflow, though limited, is the primary source of groundwater recharge. Surface water runoff and recharge in the area emanates from the Emerson, Joshua Tree, Deadman, and Mesquite watersheds. Within the Mainside Subbasin, stormwater runoff is captured within the Mainside area, combines with natural runoff from hills to the east, and is conveyed to a number of retention basins. MCAGCC has plans to reuse this captured stormwater for irrigation uses (Stetson, 2013; MCAGCC, 2015a).

The installation has access to four groundwater basins for producing water: the Surprise Spring, Deadman, Mesquite, and Mainside Sub-basins (Figure 6). MCAGCC currently produces all of its potable water from the Surprise Spring Sub-basin. There are eleven wells that are 500-700 feet deep. The wells produce ~1.8 million gallons per day (MGD). One of the wells is not presently being used as it is in a pocket of high-arsenic groundwater and requires blending. Of concern, the water table in Surprise Spring has been drawn down about 200 feet since the 1950s. The pumped groundwater is conveyed to

Mainside and stored in a series of reservoirs with a combined capacity of 15.6 million gallons (Stetson, 2014).

The Deadman Sub-Basin has low quality groundwater and has not been used in recent years. However, with MCAGCC's recent discovery that three of the Surprise Spring wells produce groundwater with elevated levels of Chrome-6, the decision was made to study whether the treatment process now required should also include treatment of Deadman Sub-basin water. That study was recently completed, and MCAGCC is planning to construct a treatment plant that will produce high quality potable water from Surprise Springs and Deadman (reducing TDS, arsenic, and fluoride levels to within MCLs). Three new wells are proposed for Deadman, and adding this source of potable water will greatly extend the life of the Surprise Spring aquifer (Stetson, 2014; MCAGCC, 2015a).

MCAGCC uses the Mainside Sub-basin to produce non-potable water for construction uses and to mix with recycled water for golf course irrigation. The Mesquite Sub-basin is not currently used by the installation.

MCAGCC has been working with the USGS for decades on basin studies and hydrologic modeling. MCAGCC recently developed groundwater models for the Mesquite and Mainside basins as part of its Salt and Nutrient Management Plan. The Water Resource Manager estimates that they have approximately 90 years of available water remaining within the Surprise Springs Sub-Basin (at a rate of use not including the planned Deadman project). No estimate is provided for once production from the Deadman Sub-basin is added to the portfolio (Stetson, 2014; MCAGCC, 2015a).

Additionally, there are two other basins of potential value: Bristol Lake Groundwater Basin and Dale Valley Groundwater Basin. These two basins are more distant from the main cantonment area of MCAGCC and extend off the installation. With the emergent plan to make use of Deadman Sub-basin, these distant basins are not currently being considered for water supplies to the installation (MCAGCC, 2015a).

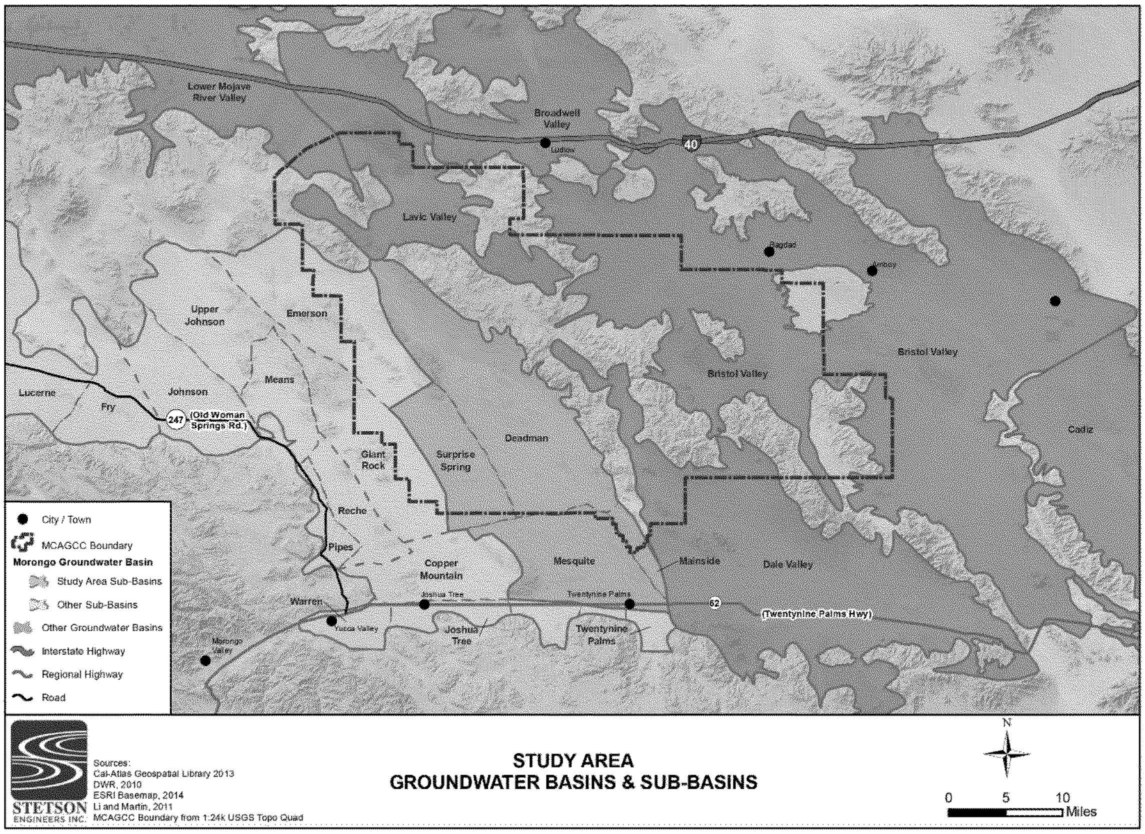

Figure 6. MCAGCC Groundwater Basins.

Meeting Executive Order mandates requires a 36% reduction in "water use intensity" from 2007 through 2025. Water conservation and efficiency measures have been aggressively employed by MCAGCC, and the installation has already achieved an impressive 56% reduction (as of FY2015). MCAGCC reports that daily per capita water use is only 69.7 gallons per day – a very low number (MCAGCC, 2015a and 2015b).

Tracking water usage is difficult on MCAGCC. Overall water production is measured, however only 183 water meters are installed across the installation, and large blocks of water users remain unmetered. The installation has contracted with a consultant to study where additional water meters should be installed (MCAGCC, 2015a). Lacking sufficient metering, it is difficult for water resource managers to monitor potential leaks, obtain feedback on the effectiveness of water conservation initiatives and education and outreach campaigns, and manage water resources.

While water is extremely valuable in the Mojave, MCAGCC does waste some water to evaporation that could otherwise be placed into use. Some recycled water is used for golf course irrigation, however part of the current wastewater treatment process includes extensive holding ponds where a significant proportion of the treated wastewater (~60%) evaporates before it can be put to use as recycled water (see Figure 7). MCAGCC has recently completed a study and has programmed military construction funding to optimize the treatment plant and control evaporation losses. The installation plans to shift from secondary to tertiary treatment process which will enable a wider set of options for recycled water application (MCAGCC, 2015a).

MCAGCC has several alternative energy projects that diversify the energy portfolio including two on-site co-generation plants that provide ~8.4 MW of power (combined); on-base photovoltaic systems that generate 1.2 MW, with 1 MW in battery capacity; a series of smaller roof-top PV sites is used across Mainside; and operation of a 10 MW micro-grid, the largest in DoD. Additional energy production projects are planned (MCAGCC, 2015a).

Federal Executive Order 13693 requires 50% solid waste diversion and a new state law, which applies to federal facilities, requires diversion of organic materials including: food waste, green waste, landscape and pruning waste, nonhazardous wood waste, and food-soiled paper that is mixed in with food waste.

The installation's waste management program has achieved a 42% rate of solid waste diversion and is exploring ways to achieve more. Managers are interested in the potential for waste-to-energy approaches as well as diversion of food waste. MCAGCC has experimented with several food-to-water methods, and managers have not been impressed with the results. They are interested in methods for macerating food from chow halls and sending it to the WWTP rather than the landfill (MCAGCC, 2015a).

Figure 7. Wastewater Treatment Plant Evaporation Pond at MCAGCC.

3.2.2 Potential Solutions

During the site visit and in subsequent conversations a number of potential solutions to MCAGCC's water, energy, and waste challenges were discussed. The following sections provide an overview of MCAGCC's planned and ongoing initiatives as well as those that may be appropriate for an EPA/ORD led effort. The intent is to examine the installation's current energy, water, and waste programs and challenges, identify specific needs and potential demonstration projects that can assist MCAGCC as it moves toward becoming net zero, and generate new scientific understanding that can be broadly applicable.

3.2.2.1 MCAGCC Planned or Ongoing Initiatives

3.2.2.1.1 Water Conservation Task Force.

The Commanding General has instituted a Water Conservation Task Force with the mission of reducing potable water use – with a special focus on eliminating use of potable water where non-potable or recycled water can meet the requirement. The Task Force meets quarterly and is composed of leaders from several staff sections and tenant organizations aboard the installation. The intent is "to make MCAGCC the example for DoD in water conservation."

3.2.2.1.2 Water Conservation

MCAGCC has implemented a number of water conservation measures such as reducing green space by 50%, increasing xeriscape (Figure 8), replacing dated fixtures with water efficient ones (i.e. shower heads, water faucet aerators, toilets), and scheduling the timing of irrigation to minimize water losses.

3.2.2.1.3 Stormwater Reuse

The installation has completed a feasibility study of stormwater capture and reuse and plans construction during FY2017. This will provide an additional 131 AFY on average.

3.2.2.1.4 Water Recycling

The installation has completed study of the WWTP optimization and plans construction during FY2018. This will reduce evaporative losses, thereby providing more (and higher quality) recycled water.

Car wash stations are also planned for FY2018; these closed-loop facilities will recycle the water and reduce runoff, water losses, and pollution.

3.2.2.1.5 Expand to New Aquifer

The new advanced water treatment plant will be constructed in FY2017-18, enabling production of groundwater from the Deadman Sub-basin.

3.2.2.1.6 Water Metering

Additional water meters will be installed across MCAGCC during FY2018, increasing situational awareness regarding water use and enabling managers to track usage rates in response to policy measures.

3.2.2.1.7 New On-site Energy

Additional on-site energy projects are being studied.

Figure 8. Xeriscape recently converted from green space at MCAGCC.

3.2.2.2 Potential EPA/ORD – led Initiatives

After touring the Twentynine Palms facilities and discussing the installation's net zero needs, EPA/ORD presented several ideas of collaborative projects that could assist MCAGCC and build on the substantial net zero-related work the installation is already doing. MCAGCC has made noteworthy progress in developing water conservation programs and policies, including the creation of a Water Conservation Task Force, which resulted in considerable water savings on the installation. Some potential projects were discussed and are described below.

3.2.2.2.1 Stormwater recharge to Surprise Springs and Deadman aquifers

There is an opportunity to extend the life of the Surprise Spring and Deadman groundwater basins through stormwater recharge. This project proposes to investigate the potential for recharge of stormwater runoff within natural channels in the Surprise Springs and Deadman Basins and reduce evaporative losses. Potential locations for injection wells would need to be identified and soil cores taken to ensure that the stormwater remains of sufficient quality as it percolates through the subsurface into the aquifer below. The investigation would also need to determine siting relative to fault lines and other geologic features that may constrain recharge.

3.2.2.2.2 Net Zero Waste

The Director of Natural Resources and Environmental Affairs has expressed a strong interest in zero waste technologies and strategies. Food waste-to-water technologies are currently being used in the chow halls, where the food waste is aerobically converted to CO2 and water. There is an opportunity to better understand the input from food waste into MCAGCC's water balance. Additionally, there remain opportunities to explore food waste source reduction, animal feed production, composting, and waste-to-energy technologies, such as pyrolysis, on the installation. EPA also has a number of tools to assist with managing waste and with analyzing approaches such as the Waste Reduction Model (WARM), the Co-Digestion Economic Analysis Tool (CO-EAT), and EPA's 2015 "Food Waste to Energy?" report (Ely and Rock 2015).

3.2.2.2.3 Water Efficiency and Metering

EPA's Water Sense program highlights best management practices for employing technologies and approaches to save water and increase water efficiency. Although installations have taken measures to reduce potable water use, there may be opportunities to explore tradeoffs with investing in additional practices. Installation of water meters are planned for a number of facilities on MCAGCC, creating an opportunity to gather informative data on water metering and its effectiveness. The knowledge gained by studying metering would be broadly applicable to other military installations. Potential benefit may be derived by evaluation of various analytics, guiding evolving procedures for use of this new source of water usage data to direct management efforts. Of interest would be the utility of this new data relative to the managerial time required for its interpretation and application to water use practices, including delivery of data to trained personnel empowered to act on the data and make or recommend decisions regarding water usage.

3.3 Edwards Air Force Base

Edwards AFB covers 481 square miles in the Western Mojave Desert northeast of Los Angeles (Figure 10). The 412th Test Wing oversees day-to-day operations and provides support for over 10,000 military, federal civilian and contract personnel who work at the installation. The 412th Test Wing plans, conducts, analyzes, and reports on all flight and ground testing of aircraft, weapons systems, software and components as well as modeling and simulation for the U.S. Air Force. There are three core components for this mission: flying operations, maintenance and engineering. The Base possesses unique attributes and capabilities and a state-of-the-art facility for its experimentation and testing mission (AFB, 2015). Figure 9 shows some of the support facilities at the flight line.

Edwards AFB is where Captain Chuck Yeager and the Bell X-1 first broke the sound barrier in 1947, where the X-15 probed the threshold of space, and where the space shuttle first landed on its initial return from earth's orbit. Edwards AFB is the test-bed for today's premiere aerospace technology programs including the Global Hawk, Hypersonic flight, and the F-35 Joint Strike Fighter.

Partners include the Air Force Research Laboratory's Propulsion Directorate, NASA's Dryden Flight Research Center, the Air Force Operational Test and Evaluation Center, and other tenant organizations (AFB, 2015).

Figure 9. Air Traffic Control Tower and hangers at Edwards AFB.

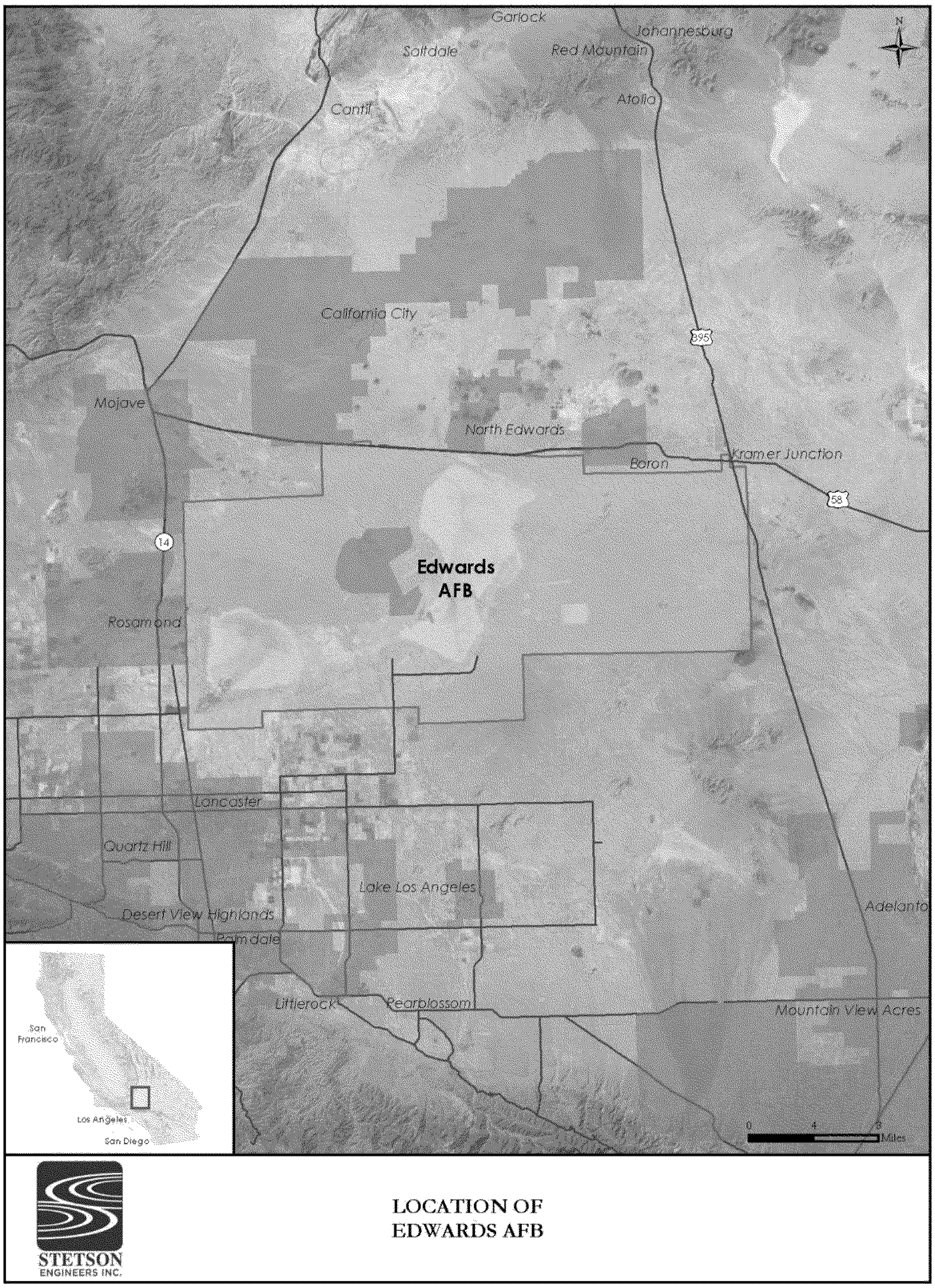

Figure 10. Location of Edwards AFB

3.3.1 Edwards AFB Challenges

The existing and long-term mission is dependent on an adequate and reliable source of water. Water demand at the installation is driven by four primary categories of use, including domestic, military, commercial/industrial, and irrigation. Key domestic uses include family housing, bachelor housing, and offices as well as the child development center, gymnasiums and swimming pools. Military uses include support for flight operations and training, mess halls, medical facilities, and clubs. Commercial/ Industrial uses are dominated by cooling units, vehicle and aircraft washing, boilers, and hydrant testing. Irrigation uses include landscaping, parade grounds, ball fields, playgrounds, and the golf course. These uses are primarily supplied by potable water sources with the exception of the golf course and ball fields, which use recycled water (AFB, 2015).

Although the installation has historically relied largely on producing local groundwater for potable uses, the Antelope Valley Groundwater Basin (see Figure 11) has been drawn down and is the subject of water rights disputes (CA DWR, 2004; AFB, 2015).

The Basin is approximately 1,600 square miles. Average annual rainfall is about 5-6 inches. The Basin has internal drainage, with runoff from the surrounding mountains draining towards dry lakebeds in the lower parts of the valley. Land use in the study area is approximately 68% natural (mostly shrubland and grassland), 24% agricultural, and 8% urban. The largest urban areas are the cities of Palmdale and Lancaster to the south (2010 populations of 152,000 and 156,000, respectively). The groundwater-flow system consists of three aquifers: the upper, middle, and lower aquifers. Historically, groundwater in the basin flowed north from the San Gabriel Mountains and south and east from the Tehachapi Mountains toward Rosamond Lake, Rogers Lake, and Buckhorn Lake. These dry lakes are places where groundwater can discharge by evaporation. Because of recent groundwater pumping, groundwater levels and flow have been altered in urban areas such as Lancaster and Edwards AFB (CA DWR, 2004).

Currently, recharge to the groundwater system is primarily runoff from the surrounding mountains, and by direct infiltration of irrigation and sewer and septic systems. The primary sources of discharge are pumping wells and evapotranspiration near the dry lakebeds. The total storage capacity for the Basin has been reported at 68-70 million acre-ft. Groundwater in this basin is used for public and domestic water supply and for irrigation (CA DWR, 2004).

Prior to 1972, groundwater provided more than 90 percent of the total water supply in the valley; since then it has provided between 50 and 90 percent. Most groundwater pumping in the valley occurs in the Antelope Valley Groundwater Basin, which includes the rapidly growing cities of Lancaster and Palmdale. Groundwater-level declines of more than 270 feet in some parts of the basin have resulted in an increase in pumping lifts, reduced well efficiency, and land subsidence of more than 6 feet in some areas. Future urban growth and limits on the supply of imported water may increase reliance on groundwater (CA DWR, 2004).

In 2011, the Los Angeles County Superior Court of California ruled that the Antelope Valley groundwater basin is in overdraft—groundwater extractions are in excess of the Court-defined safe yield of the groundwater basin. The Court determined that the safe yield of the adjudicated area of the basin was 110,000 AFY. Natural recharge is an important component of total groundwater recharge in Antelope Valley; however, the exact quantity and distribution of natural recharge, primarily in the form of mountain-front recharge, is uncertain, with total estimates ranging from 30,000 to 160,000 AFY (CA DWR, 2004; USGS, 2016c).

A judgement in the water rights case has reportedly been "verbally approved" by the Court, and issuance of the judgement is imminent. A Watermaster will be established to oversee aquifer management in accordance with the judgement on behalf of the Court (AFB, 2015).

Over time Edwards AFB has shifted from using local groundwater to using imported water. The installation now obtains about 80% of its potable water from import via the State Water Project and 20% from local groundwater. The Base does not expect the water rights judgement to negatively affect its ability to use groundwater. However the installation's water quality and quantity may be impacted by changes in land uses and water demands in the region that occur outside its boundary, as well as naturally occurring challenges. For example, the groundwater beneath the western side of the installation has elevated levels of arsenic, and groundwater is generally high in total dissolved solids (TDS) (AFB, 2015).

Use of groundwater underlying the playas, as well as surface waters flowing to the playas, is also limited by natural resource concerns: specifically that water drawdown or surface water use will increase fugitive dust emissions as well as increase surface fissuring and negatively affect playa wetland habitat, an important resource for migrating birds and native desert fauna (AFB, 2015).

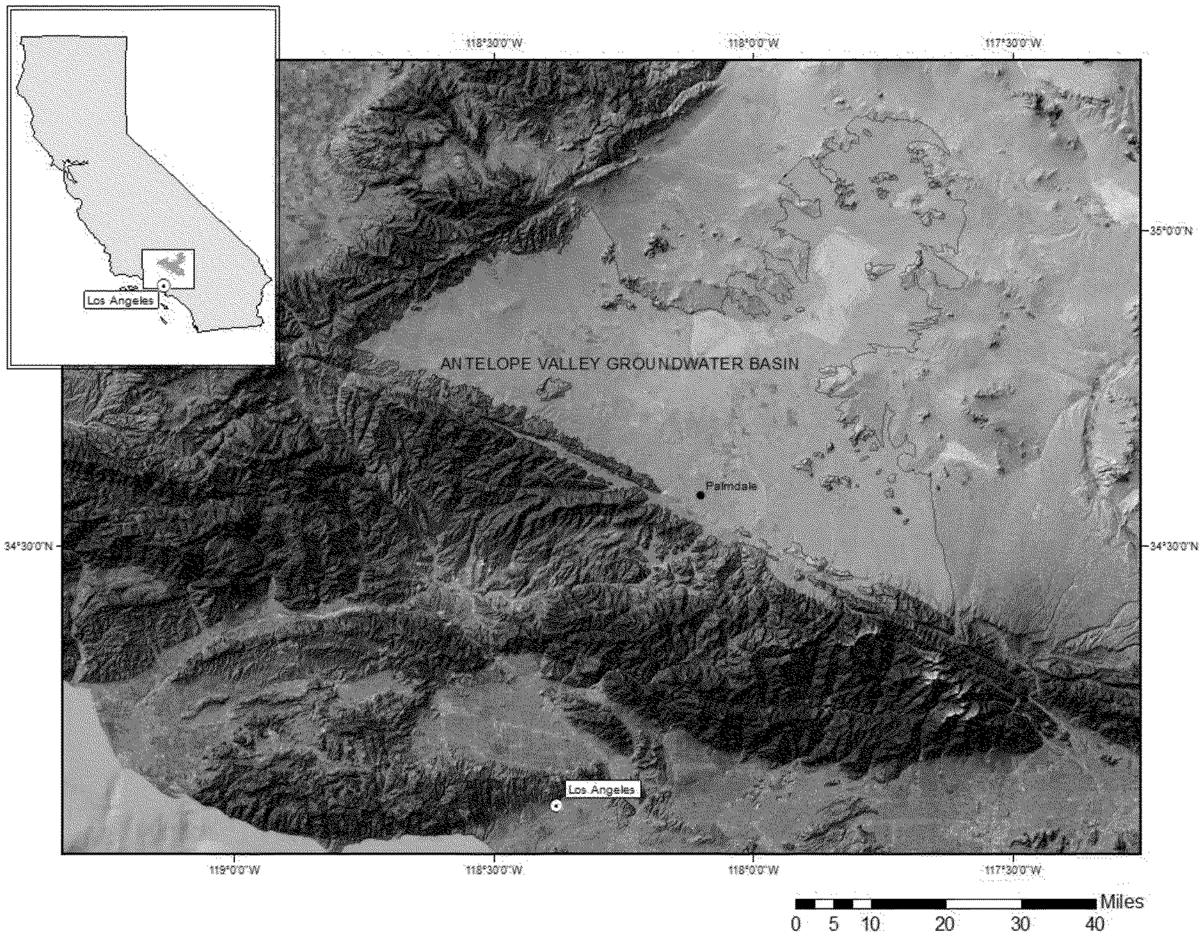

Figure 11. The Antelope Valley Groundwater Basin

Meeting Executive Order mandates requires a 36% reduction in "water use intensity" from 2007 through 2025. Water conservation and efficiency measures have been aggressively employed, and the installation has already achieved a remarkable 70% reduction in water use intensity and a 48% reduction in overall water use from 2007 levels (as of FY 2015) (AFB, 2015).

Edwards AFB has several alternative energy projects that diversify the energy portfolio including three 1-MW PV farms. Additional energy production projects are planned. The Base is seeking funding to initiate a solar generation and power storage project. An important issue to contend with in this regard is the installation's location at the end of electrical utility lines and provisions of California's Rule 21 which establishes technical requirements and procedural criteria for connecting generation equipment to the regional utility distribution systems. Installation managers state that these requirements may limit the amount of on-site energy generation the Base can develop in a cost-effective manner (AFB, 2015).

Edwards AFB has an unlined landfill and is planning to stop using the site and export its waste to a lined regional landfill located off-site (AFB, 2015). This approach lessens interest among managers in addressing waste diversion methods, although federal and state waste diversion requirements and transportation and handling costs may factor into these decisions.

3.3.2 Potential Solutions

During the site visit and in subsequent conversations a number of potential solutions to the Base's water, energy, and waste challenges were discussed. The following sections provide an overview of the installation's ongoing and planned initiatives as well as those that may be appropriate for an EPA/ORD led effort. The intent is to examine the installation's current programs and challenges, and identify specific needs and potential demonstration projects that can assist Edwards AFB as it moves toward becoming net zero, and generate new scientific understanding that can be broadly applicable.

3.3.2.1 Edwards AFB Planned or Ongoing Initiatives

3.3.2.1.1 Water Conservation

The installation has implemented a number of water conservation measures such as reducing green space and replacing dated fixtures with water efficient ones (i.e. shower heads, water faucet aerators, and toilets). Overall water use efficiency has increased tremendously.

3.3.2.1.2 Water Recycling

The installation recycles water for irrigation of the golf course and ball fields.

3.3.2.1.3 Water Metering

Additional water meters are planned for installation in the future.

3.3.2.1.4 New On-site Energy

Additional on-site energy and energy storage projects are being studied.

3.3.2.2 Potential EPA/ORD – led Initiatives

The EPA ORD team toured the facilities, discussed the installation's sustainability needs, and presented several ideas for collaborative projects that could assist the installation and build on the substantial sustainability work that Edwards AFB is already doing, including a noteworthy 48% reduction in water consumption since 2007. Some potential project topics that were discussed are described below.

3.3.2.2.1 Groundwater Recharge of Seasonally Available Recycled Water

Edwards AFB has a seasonal excess of recycled water that could be recharged to groundwater which supplies a portion of the installation's water needs. The project would direct treated wastewater to infiltration structures where it can infiltrate down to recharge the aquifer below. The research will also determine at which ground depth the evaporation zone is surpassed and gravity takes over to pull water down into the aquifer. Potential locations for injection wells would need to be identified and soil cores taken to ensure that the recycled water remains of sufficient quality as it percolates through the subsurface into the aquifer below.

3.3.2.2.2 Assess Energy and Water Resilience of Installation

Edwards AFB currently relies upon the State Water Project for most of its water, and electricity sourced from the Parker Dam Hydroelectric Generation on the Colorado River. These sources of imported water and energy may be tenuous over the long term. Additionally, they provide artificially cheap resources, skewing cost-benefit analyses of new water and energy projects. Placing a priority on efficiency or cost "is likely to eliminate consideration of redundancies that provide 'response diversity,' the different adaptation strategies or capacities inherent in different solutions to system challenges. Loss of this response diversity reduces resilience in a system." The more reliant a system is on a single resource or operating strategy, the less resilient it is and the more vulnerable to failure (Thomas and Kerner, 2010). Edwards' water and energy security could be compromised by interruption of the imported water or routing of electricity through Kramer Junction. A comprehensive assessment of Edwards AFB's energy and water resilience and security could yield insights useful for long-range planning and project justification.

3.3.2.2.3 Food Waste-to-Water

Food waste-to-water technologies, including technologies that recover animal feed from wasted food, could be employed to reduce waste sent to the landfill and add water for potential use within the recycled water system. Wastewater inflows are currently far below design capacity (up to 85% below), and the wastewater treatment process is challenged. Addition of water content from imported food (at chow halls and other centralized facilities) would add water to the overall water balance via the recycled water system.

3.3.2.2.4 Stormwater Augmentation of Recycled Water

The stormwater retention pond near Pad 7 often holds water that could potentially be routed to the wastewater collection system to augment recycled water production, supplement insufficient inflows to the wastewater treatment plant for the reasons discussed above, and reduce water lost to evaporation. There may be other stormwater detention/retention ponds that may be similarly postured to supplement recycled water supplies. There is an opportunity to better understand the significance of input from the stormwater conveyance system into the recycled water system to improve the local water balance.

3.3.2.2.5 Water Metering Analytics

Installation of water meters are planned for a number of facilities, creating an opportunity to gather informative data on water metering and its effectiveness. The knowledge gained by studying metering would be broadly applicable to other military installations. Potential benefit may be derived by evaluation of various analytics, guiding evolving procedures for use of this new source of water usage data to direct management and planning efforts.

3.4 Marine Corps Logistics Base Barstow

MCLB Barstow is a 5,567-acre installation located in San Bernardino County approximately 3.5 miles east of the city of Barstow, 134 miles east of Los Angeles, and 152 miles southwest of Las Vegas (see Figure 12). The installation was transferred from the Navy to the Marine Corps in 1942 and was called the Marine Corps Depot of Supplies. The base was designated as MCLB Barstow in 1978 (MCIC, 2013).

The installation comprises three principal sites: the Nebo Area is 1,879 acres immediately south of the Mojave River; the Yermo Annex (referred to here as "Yermo") is 1,859 acres about four miles east of Nebo on the north side of the Mojave River and between Interstates 15 and 40; the Range Complex is 2,438 acres directly south of Nebo (MCLB, 2015). Nebo functions as base headquarters and is the main facility for administration, storage, recreational activities, shopping, and housing functions. Yermo is primarily a storage and industrial complex. The Range Complex has rifle, shotgun, and pistol ranges (MCIC, 2013; MCLB, 2016b).

MCLB Barstow is a component of the Marine Corps Logistics Bases which also includes MCLB Albany, Georgia and Blount Island Command, Jacksonville, Florida. The mission of MCLB Barstow is: "To enable operational readiness through infrastructure, logistics and services in order to support Marine Corps, Army, and other government components." This mission includes procurement, maintenance, storage, and issuance of supplies and equipment for Marine Corps facilities to enable operational readiness for the Marine Corps, Army, and other government components. The mission includes rebuilding and repairing ground-combat and combat-support equipment and to support installations on the West Coast of the United States, the Far East, and Asia. MCLB Barstow hosts the Defense Logistics Agency (DLA), Fleet Support Division, Marine Depot Maintenance Command, Marine Corps Community Services, Defense Commissary Agency, United States Army Reserve Command, and several smaller tenants (MCLB, 2016c).

MCLB Barstow also supports many activities associated with a typical civilian community including retail stores, restaurants, fire stations, military police, and maintenance facilities. These tenants and training units require a reliable water supply to support a variety of military training, vehicle and equipment repair and rehabilitation, and fleet logistics chain support in keeping with the mission of the installation (MCLB, 2016c).

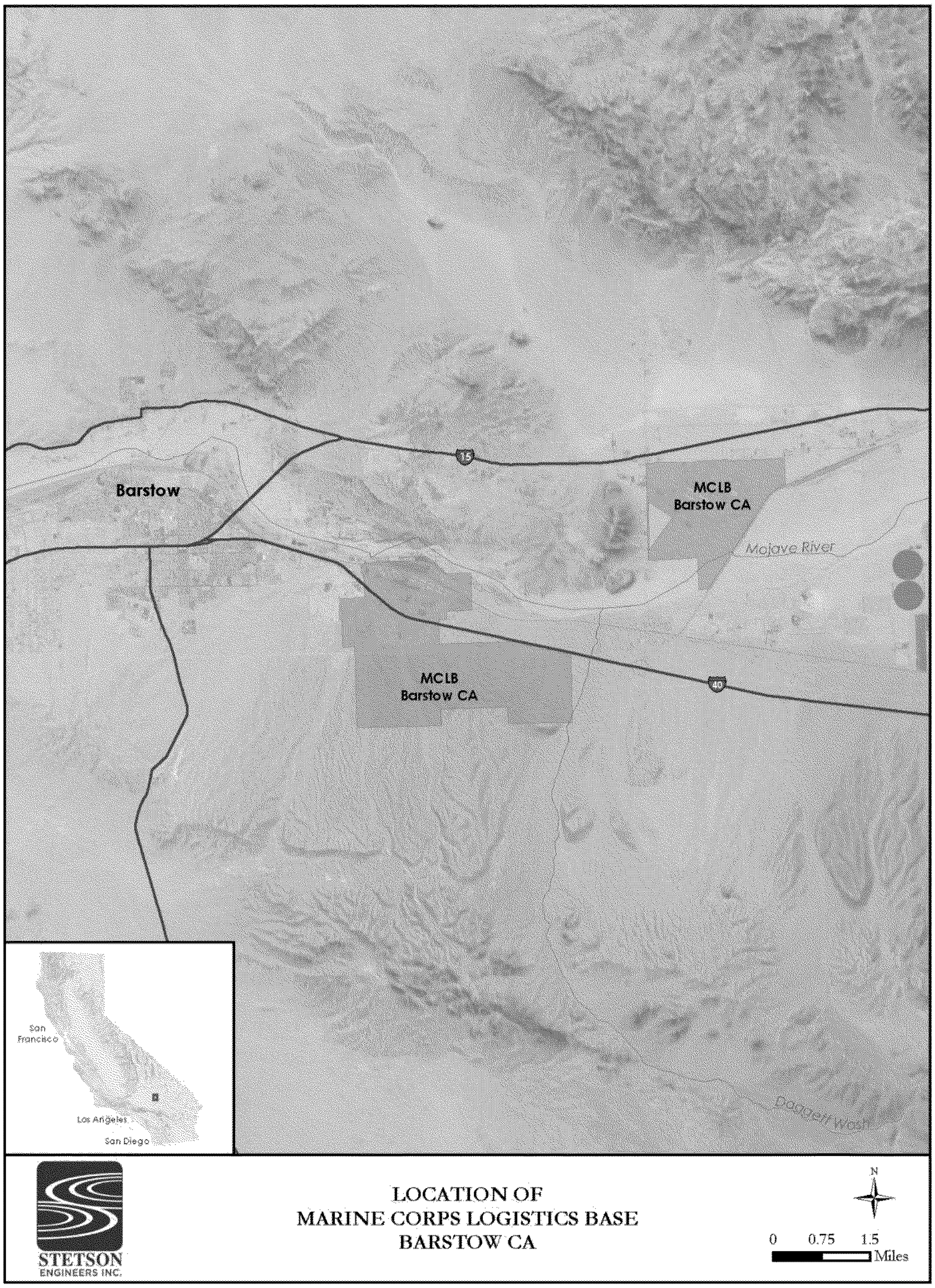

Figure 12. Location of MCLB Base Barstow - Nebo (West) and Yermo (East) Areas

The regional climate is very dry during the entire year. During the summer, the typical high temperature is 105°F degrees, humidity averages less than 40 percent, and there can be torrential thunderstorms. The average high temperature during the winter months is between 50 and 70 degrees °F. It is possible for winter temperatures to drop below freezing at night (MCLB, 2016c). Annual precipitation averages 4.4 inches at Barstow (MCIC, 2013] with higher amounts in the mountainous areas. The annual minimum recorded precipitation is 1.08 inches and the annual maximum is 10.62 inches. The majority of the precipitation falls between November and March (WRCC, 2012; MCIC, 2013).

The Mojave River is the dominant surface water feature in the area. For most of the year, and throughout the year in some dry spells, it is a dry riverbed. The river begins in the San Bernardino Mountains to the west, and it terminates at the Soda and Cronese Lakes to the east (MCIC, 2013). The river advances in a series of surface and subsurface flows. It generally flows with groundwater and reappears periodically where impermeable clays or bedrock prevent down gradient migration. The river is ephemeral for an approximately 40-mile stretch upstream of MCLB Barstow near Victorville. The riverbed remains ephemeral approximately 35 miles downstream of MCLB Barstow until the Afton Canyon (Densmore et al., 1997; MCIC, 2013).

Surface water flows and recharge of the groundwater supply are limited. Surface waters are exposed to high evaporation rates. Pan evaporation rates for the Mojave weather station, recorded between 1948 and 2005, average 111 inches per year (MCIC, 2013).

The topography is characterized by low ridges and terraces that surround and slope downward to an alluvial valley that generally trends west to east. The Rifle Range Complex contains plateaus and ephemeral washes that drain toward the Mojave River. The Nebo Area and Yermo Annex are flatter, with fewer topographic features. Within the Nebo and Yermo facilities stormwater runoff is captured within channels and is conveyed to a number of retention basins. Neither Nebo nor Yermo make use of surface water (MCLB, 2016b and 2016c).

Prior to 1977, Nebo obtained potable water from six on-site production wells for drinking and operations. In 1977, MCLB Barstow stopped using the wells for drinking water and production water because of high levels of total dissolved solids. One of the six wells was abandoned in the 1950s for unknown reasons; another well was abandoned in 1993 (MCIC, 2013; MCIWEST, 2016).

Potable water for Nebo is provided by the Golden State Water Company (MCLB, 2016a). The water company pumps this water from the Mojave Basin. The purchased water is delivered by supply lines and is stored in two on-site reservoirs, which store a total of approximately 2 million gallons of water (MCLB, 2016a). Nebo also obtains non-potable groundwater from wells onsite for use in irrigating the golf course (MCLB, 2016a).

Potable water for the Yermo area is supplied by an onsite well system. Three wells are currently used for water supply. Water from one well undergoes treatment by a Granular Activated Charcoal (GAC) system due to low water quality. The potable water is stored in a number of reservoirs throughout the base.

The treated water is pumped via booster pumps to an elevated storage tank that provides additional pressure to the system (MCIWEST, 2016; MCLB, 2016a and 2016c).

3.4.1 MCLB Barstow Challenges

All water used in the Barstow area is local groundwater from the Mojave River Groundwater Basin. The Basin covers an area of approximately 3,400 square miles. Large portions of the Basin have been in over draft conditions for many decades. Groundwater production has increased greatly, starting in the late 1940s (USGS, 2016a). Records show that depth to water in regional wells has been increasing steadily. From the 1940s to 2010, several wells at and near Yermo show an approximately 100-105 foot drop in the water table (Stamos et al., 2001; USGS, 2016b). Groundwater modeling has revealed that overdraft existed as early as the 1960s, and cumulatively the entire Basin is 2.5 million AF in overdraft. Nebo overlies the Centro Subarea, which is estimated to be ~750,000 AF in overdraft. Yermo overlies the Baja Subarea, which is estimated to be ~1,100,000 AF in overdraft (Stamos et al., 2001).

The Basin is now producing groundwater under an adjudicated judgment. Part of the physical solution enacted entails aquifer recharge, and the Mojave Water Agency imports and recharges water from the State Water Project (SWP), water that is sourced from the Sacramento and San Joaquin Rivers (USGS, 2016a). A pipeline from the SWP California Aqueduct junction near the City of Adelanto conveys water down the Mojave River valley past Barstow (see Figure 13). This spur system is operated by the MWA. The imported water is not currently placed into direct use; rather, it is used to recharge the aquifer (MWA, 2016). MWA's maximum annual entitlement from the SWP is 85,800 AFY from 2015 to 2019 and 89,800 AFY from 2020 to 2035 (GSWC, 2011).

Deliveries of imported water for recharge depends on availability and priority. The drought has halted any meaningful deliveries to the area recently; during 2015 there were no deliveries to the area (MCIWEST, 2016; MWA, 2016).

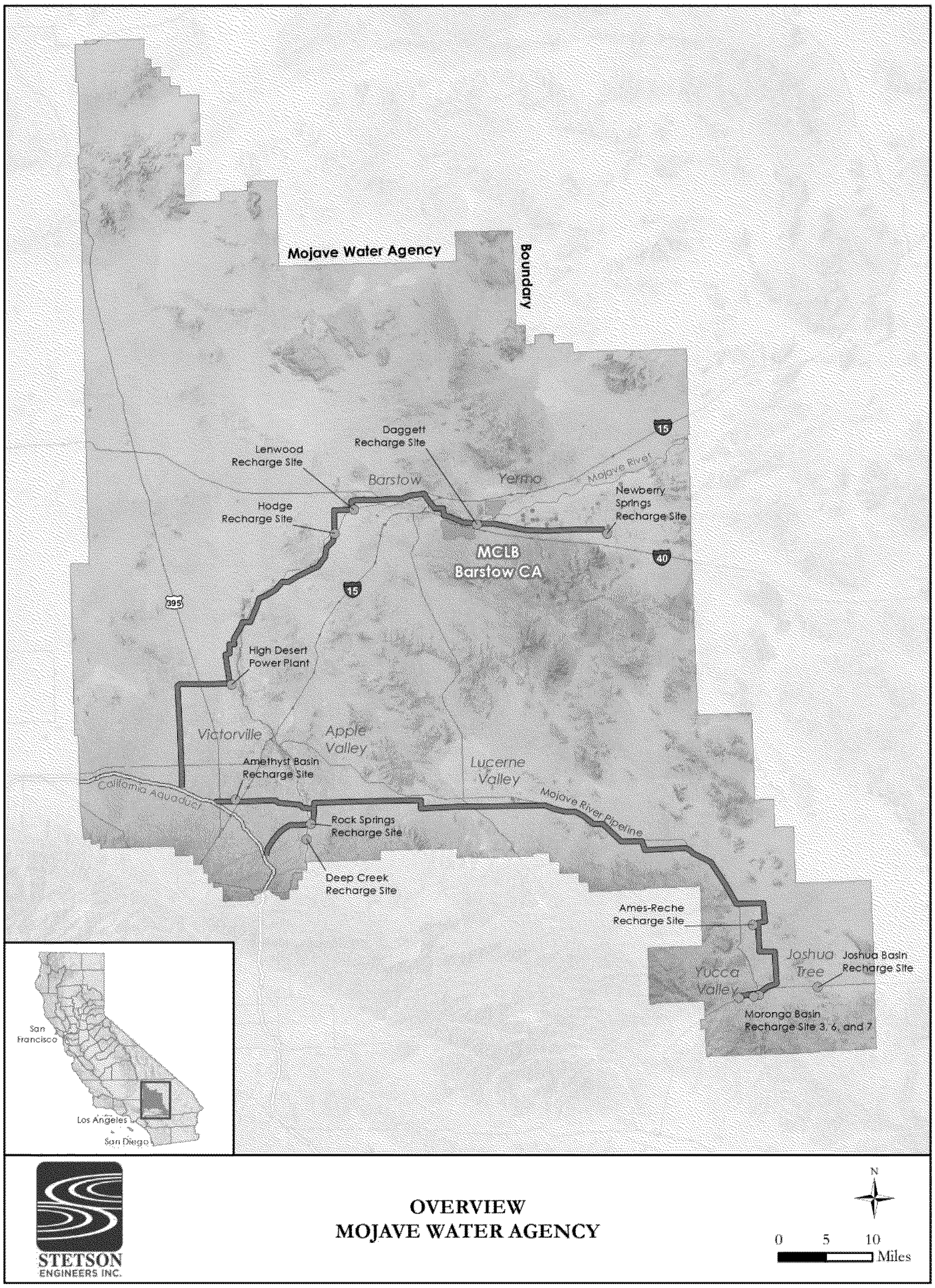

Figure 13. Mojave River Groundwate r Basin and Regional Recharge Facilities

The installation faces several long-term water quality challenges. Contaminated groundwater (hexavalent chromium) from the Hinkley plume is migrating toward MCLB. It is projected to reach Nebo within 29 years and Yermo within 77 years at present rates of movement. Additionally, there is a nitrate plume (~40 mg/L) much closer to the Depot. It is migrating from the City of Barstow toward MCLB (MCLB, 2016b).

The domestic wastewater systems at Nebo and Yermo are experiencing greatly decreased flow rates due to the decrease in base population. The existing wastewater pumps are oversized and the domestic WWTPs are larger than what is needed for the existing base population. The decrease in influent has adversely affected the denitrification process for the domestic wastewater systems (MCLB, 2016b and 2016c).

MCLB Barstow lacks metering for most of its water use and thus is not able to fully characterize where water is used or how the rate of use for various purposes responds to changes in policies (MCLB, 2016a and 2016b).

While the potential for on-site alternative energy generation is quite high, actual generation at the time of EPA's visit was limited by Net Energy Metering (NEM) provisions. In fact, the large wind turbine at Nebo was being run below capacity and a roof-top PV system had been installed but could not be placed into use (MCLB, 2016b).

3.4.2 Potential Solutions

During the site visit at the Nebo and Yermo facilities, a number of potential solutions to the water, energy, and waste challenges were discussed. The following sections provide an overview of the installation's planned and ongoing initiatives as well as those that may be appropriate for an EPA/ORD led effort. The intent is to examine the installation's current energy, water, and waste programs and challenges, and identify specific needs and potential demonstration projects that can assist MCLB Barstow as it moves toward becoming net zero, and generate new scientific understanding that can be broadly applicable.

3.4.2.1 MCLB Barstow Planned or Ongoing Initiatives

MCLB Barstow has made noteworthy progress in developing water, energy, and waste management programs and policies.

The installation has also made improvements in domestic wastewater treatment on Yermo to enable percolation and recharge of treated effluent rather than losses through evaporation.

3.4.2.1.1 Water Conservation
The installation has implemented a number of water conservation measures such as reducing green space and replacing dated fixtures with water efficient ones (i.e. shower heads, water faucet aerators, toilets). The Depot has plans for removal of more trees and turf.

3.4.2.1.2 Water Recycling
The installation recycles industrial wastewater. This is available for use at Yermo, however it is infrequently used. MCLB does not currently make use of domestic recycled water.

3.4.2.1.3 Groundwater Recharge of Treated Wastewater
During 2015 MCLB Barstow made repairs to the domestic wastewater treatment plant at Yermo and is now able to meet permit requirements for percolating effluent to recharge groundwater. Such measures are being studied for the domestic WWTP at Nebo, which currently must evaporate all treated wastewater.

3.4.2.1.4 Water Metering.
Additional water meters are planned for installation in the future.

3.4.2.1.5 New On-site Energy.
Approximately 1,333 KW of renewable energy has been developed onsite at Nebo and 666 KW of renewable energy onsite at Yermo (plus 500 KW of photovoltaic lighting). Additional on-site energy and energy storage projects are being studied.

3.4.2.2 Potential EPA/ORD – led Initiatives
The EPA/ORD team toured the facilities, discussed the installation's sustainability needs, and presented several ideas of collaborative projects that could assist the installation and build off of the substantial sustainability work that MCLB Barstow is already doing. Some potential project topics were discussed and are described below.

3.4.2.2.1 Centralized Storage and Distribution of Non-potable Water
This project entails developing a network that consolidates collection, storage, and delivery of non-potable water at Yermo. The water sources would include: recycled water from the domestic WWTP; recycled water from the industrial WWTP; and potentially non-potable groundwater and collected stormwater. This resource would serve non-potable uses currently being served by potable water. A cost-benefit analysis would be performed to determine return on investment, as well as progress toward water and energy conservation goals and savings in the water balance for MCLB.

3.4.2.2.2 Stormwater Capture and Use
MCLB Barstow has a large number of warehouses and maintenance buildings. This project proposes to investigate the potential for capturing and collecting rooftop stormwater from these buildings and other runoff and making use of this water to augment non-potable water resources for non-potable needs. There is an opportunity to better understand the significance of input from stormwater into the recycled water system to improve the local water balance.

3.4.2.2.3 Stormwater Recharge to Mojave River Groundwater Basin

MCLB Barstow (and the civilian community outside the Base) uses the Basin for all water needs. There is an opportunity to extend the life of this sole-source groundwater basin through stormwater recharge. This project proposes to investigate the potential for enhancing recharge of stormwater through green infrastructure design. Potential locations for injection wells would need to be identified and soil cores taken to ensure that there are no impediments to the stormwater reaching and recharging the Basin, and that the water remains of high quality as it percolates through the subsurface into the aquifer below. The research will also determine at which ground depth the evaporation zone is surpassed and gravity takes over to pull water down into the aquifer. This research would be instrumented to measure the efficacy of infiltration and recharge. The knowledge gained would be applicable not only for MCLB Barstow, but also more broadly within the Basin and across the Mojave. Potential benefit may be derived by evaluation of various analytics, guiding evolving procedures for development of this water source.

3.4.2.2.4 Net Zero Waste

There are opportunities to explore reusing, recycling or selling of blast grit, and/or appropriate waste-to-energy technologies on the installation (of which 2 - 2.5 million pounds per year is produced).

3.5 Naval Air Weapons Station (NAWS) China Lake

NAWS China Lake is located in the Western Mojave Desert, just east of the southern Sierra Nevada range and approximately 150 miles (240 km) north of Los Angeles (see Figure 14). Occupying three counties – Kern, San Bernardino and Inyo – the installation is very large and remote. Its closest neighbors are the cities of Ridgecrest, Inyokern, Trona and Darwin (NAWS, 2016a).

NAWS China Lake is the Navy's largest single landholding, representing 85 percent of the Navy's land for weapons and armaments research, development, acquisition, testing and evaluation (RDAT&E) use and 38 percent of the Navy's land holdings worldwide. In total, its two ranges and main site cover more than 1,100,000 acres (4,500 km^2), an area larger than the state of Rhode Island. As of 2010, at least 95 percent of that land has been left undeveloped. The 19,600 square miles (51,000 km^2) of restricted and controlled airspace at China Lake makes up 12 percent of California's total airspace. Jointly-controlled by NAWS China Lake, Edwards Air Force Base and Fort Irwin, this airspace is known as the R-2508 Special Use Airspace Complex (Global Military, 2016).

The installation falls under the jurisdiction of Navy Region Southwest under Commander, Navy Installations Command. The installation is home to a number of tenant Commands and organizations including (Global Military, 2016):

- The Naval Air Warfare Center Weapons Division, which maintains a center of excellence in weapons development for the Department of the Navy
- Air Test and Evaluation Squadron THREE ONE (VX-31), which provides the resources, expertise and support needed to plan and execute safe and efficient ground and flight tests of developmental weapons and weapons systems
- Air Test and Evaluation Squadron NINE (VX-9), which conducts operational test and evaluation of all air-to-ground weapons, air-to-air weapons, sensors, electronic warfare systems and mission software upgrades to aircraft and weapon systems
- Marine Aviation Detachment, which is on the cutting edge of technology for weapons, weapon systems, electronic warfare development, testing and evaluation
- Navy Explosive Ordnance Disposal
- NAVFAC Southwest, Public Works Department China Lake, which is responsible for the public works, planning, engineering/design, construction, real estate, environmental services, and acquisition / disposal of facilities and real estate at NAWS China Lake

The installation also supports many activities associated with a typical civilian community including retail stores, restaurants, fire stations, military police, and maintenance facilities in the main cantonment area (see Figure 15). These organizations require a reliable water supply to support a variety of functions in support of the mission of the installation (NAWS, 2016a).

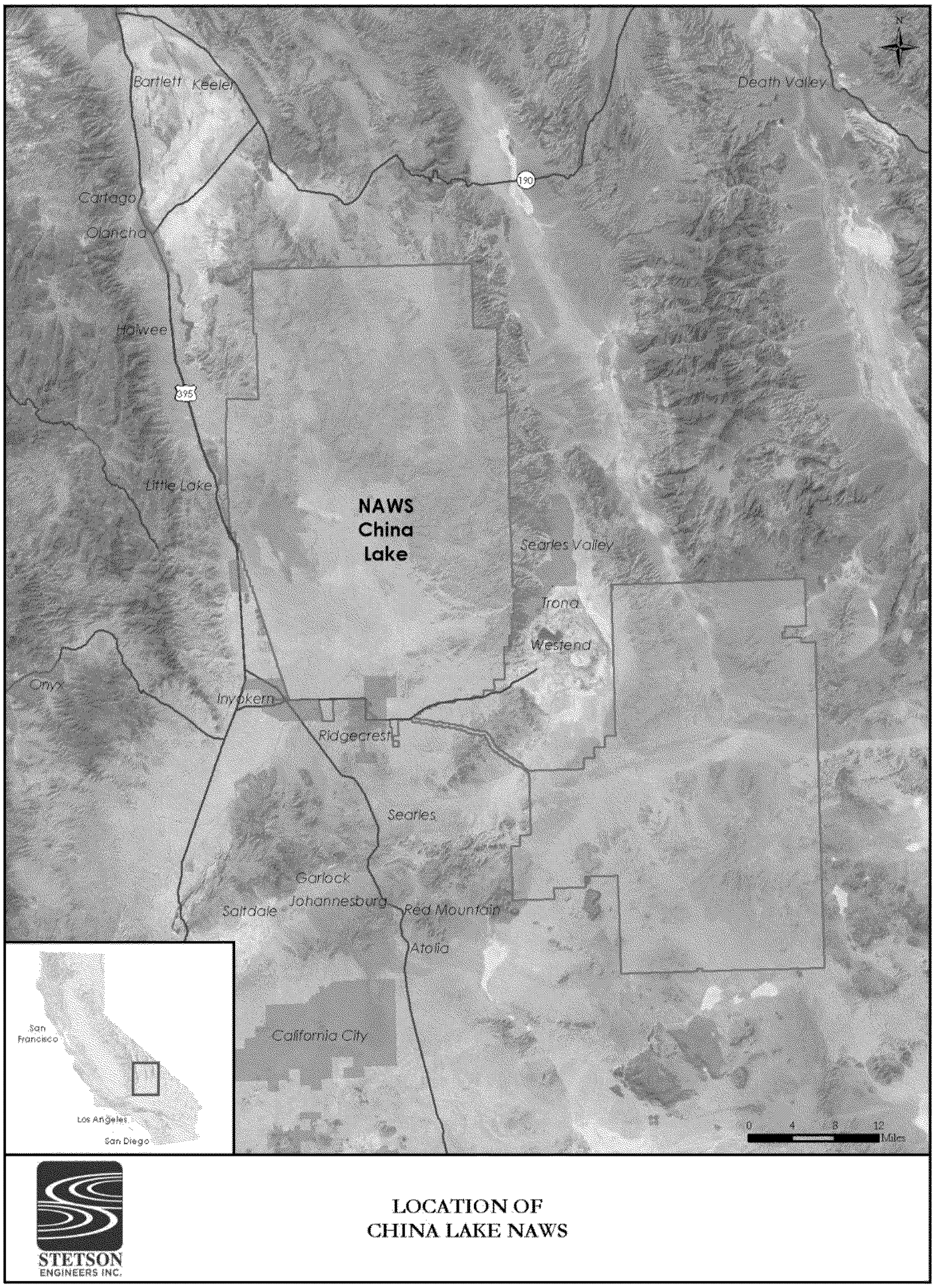

Figure 14. China Lake NAWS Location

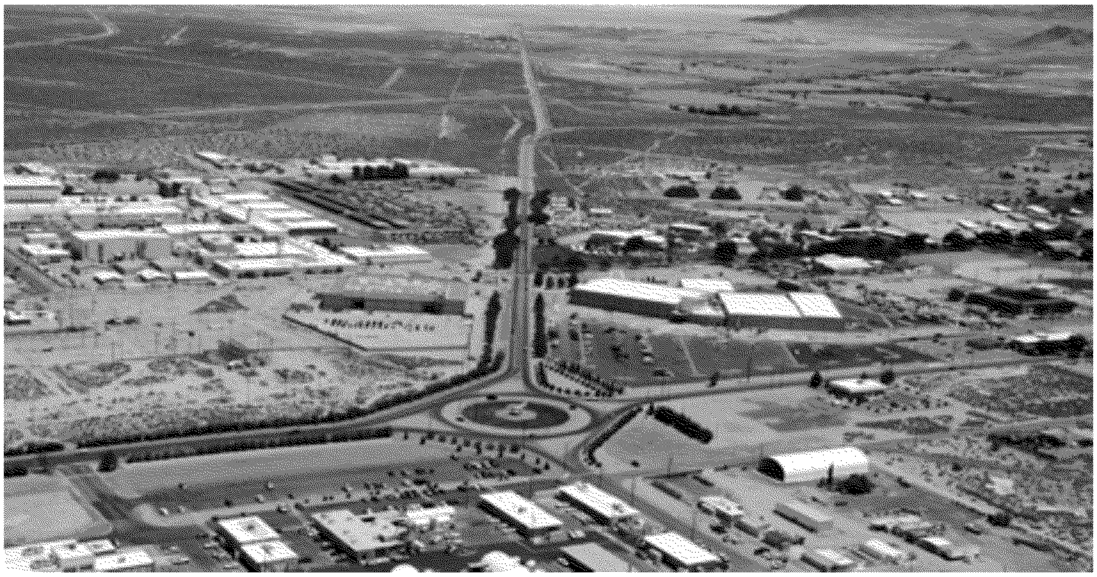

Figure 15. Main Cantonment Area of China Lake NAWS

The main cantonment area of the Station has water and wastewater service. A few remote areas are serviced by wells and sewage leach fields, however most remote areas have no water or wastewater service. All water used in the China Lake area is local groundwater from the Indian Wells Valley (IWV) Groundwater Basin (NAWS, 2016a and 2016b) (Figure 16). Average annual precipitation in the valley is about 4 to 6 inches. Surface elevation in the central Indian Wells Valley ranges from 2,150 to 2,400 feet above sea level. The basin is a closed, internally drained basin bounded by outcrop of igneous and metamorphic basement rock complexes. The Sierra Nevada Range bounds the basin on the west, the Coso Range on the north, the Argus Range on the east, and the El Paso Mountains on the south. China Lake, a perennial lake, is situated in the central northeastern valley and is the primary natural groundwater discharge point (CA DWR, 2004).

Pleistocene to Holocene age lakebed, stream and alluvial fan deposits comprise the primary water-bearing formations. The aquifer is divided into an upper aquifer and a lower aquifer. The lower aquifer is the primary producer for this basin. The upper aquifer does not yield water freely to wells, and consists of poor quality water. The lower aquifer is larger, with a saturated thickness of up to 1000 feet in the central part of the valley. The lower aquifer is considered unconfined except in the eastern part of the valley where the aquifer is confined by silt and clay lenses, lake deposits, and playa deposits. Well yields in the lower aquifer are more than 1,000 gallons per minute (gpm) and some wells consistently yield more than 2,000 gpm. Storage capacity for the basin is estimated to be between 2,200,000 and 5,120,000 AF (CA DWR, 2004). Groundwater flow under natural conditions was from the lower aquifer to the upper aquifer and flowed through the lower aquifer from the areas of recharge along the southwest, west, north, and northeast edges of the valley toward China Lake playa. However, human activities in the valley including pumping and sewage effluent recharge have altered natural flow (CA DWR, 2004).

There are many types of groundwater quality in Indian Wells Valley and vicinity. TDS for these waters range from less than 600 mg/L to more than 1,000 mg/L (CA DWR, 2004). Thirty three Title 22 wells sampled have TDS concentrations ranging from 192 to 950 mg/L with an average concentration of 390 mg/L (CA DWR, 2004). The installation produces good quality water from wells near Inyokern (TDS is ~200 mg/L) (NAWS, 2016b)

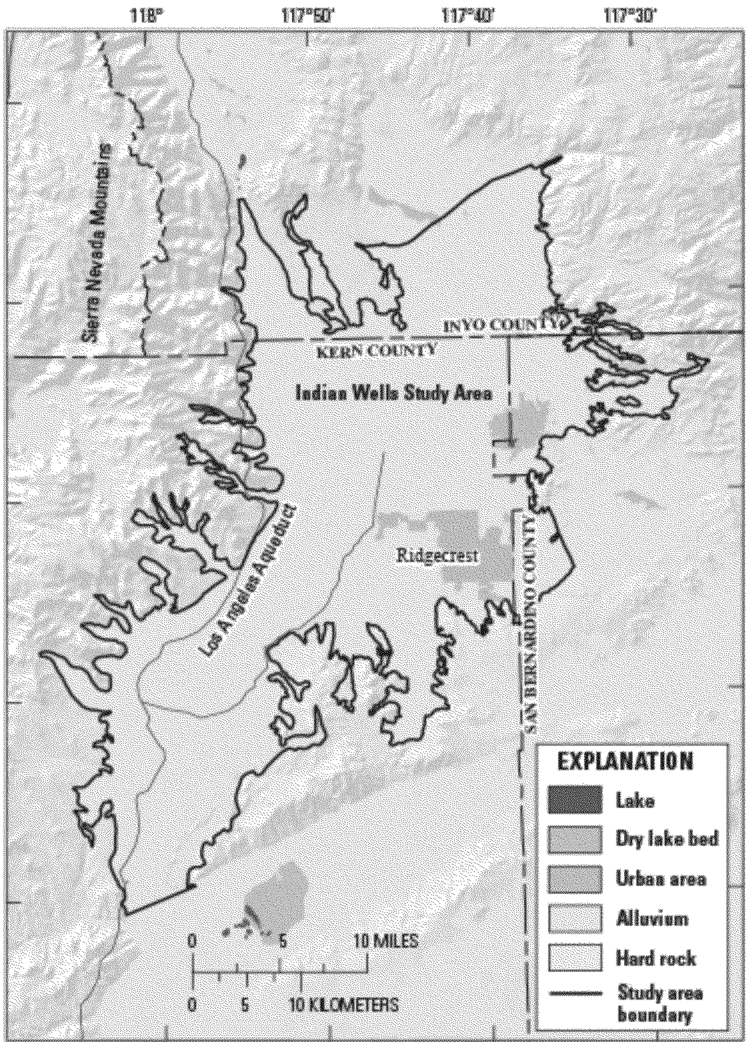

Figure 16. Indian Wells Valley Groundwater Basin

3.5.1 China Lake NAWS Challenges

China Lake NAWS and the civilian communities, as well as the alfalfa pistachio growers use the groundwater in the basin for all water needs. There is no water imported to this area. Groundwater levels have been declining since 1945 (CA DWR, 2004). As a result of pumping, a regional cone of depression has formed approximately three miles northwest of the City of Ridgecrest. Hydraulic heads have changed in the shallow aquifer, due to effluent recharge, causing it to leak into the deep aquifer and migrate towards the cone of depression. This leakage is of concern because of the shallow aquifer's historically poor water quality. Water quality in areas of geothermal waters may be poor with high levels of chloride and in many cases, high boron and arsenic (CA DWR, 2004).

In 2015 the California Department of Water Resources (DWR) pursuant to the Sustainable Groundwater Management Act (SGMA) identified the Indian Wells Valley Groundwater Basin as in "critical conditions of overdraft."

In 2016 a Groundwater Sustainability Agency was established to plan for and regulate use of groundwater in the basin (CA DWR, 2014). The GSA is made up of representatives from Kern, Inyo and San Bernardino counties as well as the IWV Water District and the City of Ridgecrest. China Lake NAWS and the Bureau of Land Management are non-voting members (Bakersfield.com, 2016). Prior to January 31, 2020, the GSA must adopt a Groundwater Sustainability Plan and reach sustainability within 20 years.

Development of additional onsite renewable energy facilities is constrained by regional interconnect rules that limit the cost-effectiveness of such projects (Rule 21).

3.5.2 Potential Solutions

During the site visit and in subsequent conversations a number of potential solutions to water, energy, and waste challenges were discussed. The following sections provide an overview of the installation's planned and ongoing initiatives as well as those that may be appropriate for an EPA/ORD led effort. The intent is to examine the installation's current energy, water, and waste programs and challenges, identify specific needs and potential demonstration projects that can assist China Lake NAWS as it moves toward becoming net zero, and generate new scientific understanding that can be broadly applicable.

China Lake NAWS is mandated to meet stringent Executive Order goals for water and energy management, and the installation has made noteworthy progress in developing water conservation programs and policies, achieving approximately 50% reduction in water use since 2007 and approximately 33% on-site renewable energy generation (NAWS, 2016a). However making future progress will be challenging given that the "low hanging fruit has already been picked," hence the installation may need to adopt new technologies and expend additional resources to meet the reduction targets.

There are collaborative opportunities for achieving water sustainability. The installation is currently collaborating with neighboring stakeholders under the auspices of the IWV Cooperative Groundwater Management Group and the new GSA that is being formed for the Basin (NAWS, 2016a).

Some potential project topics were discussed with installation personnel, as described below.

3.5.2.1 China Lake NAWS Planned or Ongoing Initiatives

3.5.2.1.1 Water Conservation

The installation has implemented a number of water conservation measures such as reducing green space and replacing dated fixtures with water efficient ones (i.e. shower heads, water faucet aerators, toilets).

3.5.2.1.2 Water Recycling

The installation recycles about 270 AFY of water for irrigation of the golf course (NAWS, 2016b).

3.5.2.1.3 Water Metering

Additional water meters are planned for installation in the future.

3.5.2.1.4 New On-site Energy

The installation produces about 33% of the electricity it requires onsite (NAWS, 2016a). Additional on-site energy and energy storage projects are being studied.

3.5.2.1 Potential EPA/ORD – led Initiatives

3.5.2.1.1 Stormwater Recharge to Indian Wells Valley Groundwater Basin

There is an opportunity to extend the life of this sole-source groundwater basin through stormwater recharge that may be achievable within the Cantonment Area and outside of it. There may be an opportunity to work closely with the City of Ridgecrest and the other stakeholders within the IWV Cooperative Groundwater Management Group and the Groundwater Sustainability Agency (GSA) being formed for the Basin. There are two versions of this project discussed below.

3.5.2.1.1.1 Recharge Outside of Cantonment

This project proposes to investigate the potential for recharge of stormwater runoff within natural channels and reduce evaporative losses. Potential locations for injection wells would need to be identified and soil cores taken to ensure that there are no impediments to the stormwater reaching and recharging the Basin, and that the water remains of sufficient quality as it percolates through the subsurface into the aquifer below to be useful in the future. The research will also determine at which ground depth the evaporation zone is surpassed and gravity takes over to pull water down into the aquifer.

3.5.2.1.1.2 Recharge within Cantonment / Urban Areas

This project proposes to investigate the potential for enhancing recharge of stormwater through green infrastructure design. This project is similar to the one above, however it would address the special challenges inherent to developing recharge within an urban setting. As an example of how much water might be available for recharge, Marine Corps Air Ground Combat Center is planning a similar stormwater capture and reuse project that would obtain about 131 AFY on average from a watershed of 1460 acres to augment existing water sources.

This project could be done in cooperation with the IVW GSA. The project would be instrumented to function as a “test bed” measuring the efficacy of infiltration and recharge. The knowledge gained would be applicable not only for China Lake and the nearby civilian community, but also more broadly across the Mojave. Potential benefit may be derived by evaluation of various analytics, guiding evolving procedures for development of this water source.

3.5.2.1.2 Maximize Use of Non-Potable Water Resources

This project proposes to study methods for making use of non-potable water resources in substitution for the potable groundwater currently being depleted. This project could be done with a focus on China Lake NAWS, or in cooperation with the IVW GSA and a Basin-wide focus. The project would entail a cost-benefit analysis of continuing to use potable groundwater and recycled water for current uses versus development of a system that also makes use of captured stormwater and non-potable and brackish groundwater. The strategies examined would include integrated systems and decoupled stand-alone applications for specific uses, as well as stormwater diversion and injection, stormwater capture and use, and indirect potable reuse of recycled water.

4 Recommendations

The following research projects are recommended for consideration within this collaborative EPA-DoD initiative. There is one project for each installation visited. While EPA is amenable to pursuing any of the potential projects discussed in Section 3 above, the projects below appear to be well aligned with the EPA research objectives (see Appendix C) and DoD installation needs. They also present opportunities for technology transfer and wider application within DoD as well as other federal organizations and civilian communities.

Additionally, these efforts would be supported through an additional MOU between EPA/ORD and the Department of the Navy, and enhanced by greater regional-scale coordination through current mechanisms, and/or a project advisory group.

The first project below has a project prospectus in Appendix D, which is provided as an example of what can be developed to facilitate further discussions regarding next steps in this initiative.

4.1 Recommended Technology Demonstration Opportunities

4.1.1 Fort Irwin NTC - Focused Recharge: Prioritizing Percolation of Treated Wastewater in an Arid Environment

Fort Irwin's water supplies are limited and diminishing. Surface water is ephemeral and insufficient as a source of direct supply. Installation managers, working with the USGS, estimate that they have a total of 50-70 years of available water remaining within the three groundwater basins currently in use.

Fort Irwin also has a seasonal excess of recycled water that could be recharged to groundwater. The project would direct Fort Irwin's treated wastewater to infiltration structures within a stormwater conveyance channel where it can infiltrate down to recharge the aquifer below. The research will also determine at which ground depth the evaporation zone is surpassed and gravity takes over to pull water down into the aquifer. This project is discussed further in Appendix D.

The findings of this study would be applicable to potential recharge projects across the region.

4.1.2 MCAGCC Twentynine Palms - Net Zero Waste

The installation has a strong interest in zero waste technologies and strategies. Food waste-to-water technologies are currently being used in the chow halls, where the food waste is aerobically converted to CO2 and water. There is an opportunity to better understand the input from food waste into MCAGCC's water balance and explore emerging food waste to water and animal feed recovery technologies.

The findings of this study would be applicable to potential waste to water and waste to energy projects on other military installations and in civilian communities nationally.

4.1.3 Edwards AFB - Assess Energy and Water Resilience of Installation

Edwards AFB currently relies upon the State Water Project for most of its water, and electricity sourced from the Parker Dam Hydroelectric Generation on the Colorado River. Managers recognize that these sources of imported water and energy may be tenuous over the long term. Additionally, these sources provide artificially cheap resources, skewing cost-benefit analyses of new water and energy projects. Placing a priority on efficiency or cost "is likely to eliminate consideration of redundancies that provide 'response diversity,' the different adaptation strategies or capacities inherent in different solutions to system challenges. Loss of this response diversity reduces resilience in a system." The more reliant a system is on a single resource or operating strategy, the less resilient it is and the more vulnerable to failure (Thomas and Kerner, 2010). Edwards' water and energy security could be compromised by interruption of the imported water or routing of electricity through Kramer Junction. A comprehensive assessment of Edwards AFB's energy and water resilience and security could yield insights useful for long-range planning and project justification.

This resilience assessment responds not only to installation needs; senior DoD decision-makers have called for the means to instill and manage resilience in their programs. Frustrated with inadequate, incompatible, and uncoordinated management policies, strategies, and tools that cannot accommodate resilience analysis, they have openly sought resilience metrics that would enable prioritization of activities and allocation of resources (Kidd, 2012; Mitchell, 2014; Nagel, 2014). This assessment would seek to bridge the gap from resilience theory to actionable science, action plans, and metrics.

The findings of this study would be applicable to DoD installations, regional Commands, and federal facilities nationwide. The knowledge gained in this research would also extend to civilian communities facing the same energy and water challenges.

4.1.4 MCLB Barstow - Centralized Storage and Distribution of Non-potable Water

This project entails developing a network that consolidates collection, storage, and delivery of non-potable water at Yermo. The water sources would include: recycled water from the domestic WWTP; recycled water from the industrial WWTP; and potentially non-potable groundwater and collected stormwater. This resource would serve non-potable uses currently being served by potable water. A cost-benefit analysis would be performed to determine return on investment, as well as progress toward water and energy conservation goals and savings in the water balance for MCLB.

The findings of this study would be applicable to potential non-potable water projects across the region and nationally.

4.1.5 China Lake NAWS - Recharge Within Cantonment / Urban Areas

This project proposes to investigate the potential for enhancing recharge of stormwater through green infrastructure design. There is an opportunity to extend the life of the Indian Wells Valley Groundwater Basin, a vital, sole-source groundwater basin. There may be an opportunity to work closely with the City of Ridgecrest and the other stakeholders within the IWV Cooperative Groundwater Management Group and the Groundwater Sustainability Agency (GSA) being formed for the Basin. The project would be instrumented to function as a "test bed" measuring the efficacy of infiltration and recharge.

The knowledge gained would be applicable not only for China Lake and the nearby civilian community, but also more broadly across the Mojave. Potential benefit may be derived by evaluation of various analytics, guiding evolving procedures for development of this water source.

4.2 Recommendations for Enhanced Support and Regional Coordination

4.2.1 MOU with the Department of the Navy

In discussions with the Navy installations, it became clear that an MOU between EPA/ORD and the Navy would underpin, and provide a framework for any projects at MCAGCC Twentynine Palms, NAWS China Lake, and MCLB Barstow. This MOU, similar to the one between EPA/ORD and the Army, could outline general principles and goals and a framework for the science, research, development, and technology demonstrations needed to support those goals.

4.2.2 Enhanced Regional Coordination

Given the shared resources and shared challenges among the installations, as well as the potential for similar solutions, there would clearly be a benefit to collaboration and coordination on a regional scale in the Mojave. It is recommended that this regional scale coordination be explored through the Desert Managers Group (DMG), which was established as a forum for government agencies operating in the Mojave Desert region to address and discuss issues of common concern. Additionally, depending on the number of projects that develop out of this effort, it could be useful to charter a project advisory group from the participating installations to enhance cooperation at a regional scale.

These projects, the MOUs to underpin them, and the regionally-coordinated efforts support integrated decision making at participating installations and operational efficiencies. These efficiencies will enable installations to more effectively and efficiently direct efforts and funds to increase their sustainability, develop an optimal portfolio for integrated water, energy, and waste management, and increase their overall resilience. The installations, in collaboration with EPA/ORD, can develop an adaptive energy-water-waste resource management portfolio consisting of technologies and behavioral changes that directly contribute to the long-term resilience of an installation, individually as well as the multi-service Mojave Range Complex. Chiefly, water management strategies or technologies deemed the most suitable for creating resilient desert-based installations will be transferable to non-military communities in the region and potentially across the U.S. This overall effort will promote resource conservation and management in the context of the federal agency mission. EPA/ORD will benefit from the opportunity to further apply and enhance its tools and models to sustainable water use challenges, integrating amongst water-energy, and waste recovery-water systems. All efforts will complement on-going research and will be consistent with the focus of ORD's research efforts on sustainable communities, systems thinking, environmental protection, and decision-support analyses.

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Appendix A Regulatory and Legal Drivers

Federal Laws and Regulations

The Safe Drinking Water Act (SDWA) is the main federal law that ensures the quality of drinking water. Under SDWA, the EPA sets standards for drinking water quality and oversees the states, localities, and water suppliers who implement those standards. The SDWA requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells.

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The CWA makes it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit is obtained. The National Pollutant Discharge Elimination System (NPDES) permitting program controls discharges.

The Resource Conservation and Recovery Act (RCRA) establishes solid waste management requirements and promotes resource conservation and recovery.

Other environmental regulations, such as those that implement the Endangered Species Act (ESA), affect water resource management indirectly by constraining management choices that may affect listed threatened and endangered species and habitat.

The Mojave installations are also subject to an increasing range of requirements that impact water security and must demonstrate progress toward a range of water management and conservation goals (e.g. EPAct 2005 and EISA 2007). Executive Order (EO) 13423 mandates water use intensity reductions and requires that new construction and renovation designs comply with the sustainable guiding principles. EOs 13514 and 13693 further enhance water use reduction mandates including consideration for non-potable water. In compliance with these Orders, military installations are required to reduce potable water consumption intensity (consumption based on building space) by 2% annually from the baseline FY 2007 through FY 2025. The Marine Corps must also reduce industrial, landscape irrigation, and agricultural (ILA) water uses by 2% annually from FY 2010 through FY 2025. The Defense Utility Energy Reporting System (DUERS) Instruction establishes a standardized process for all Installation Commands to report potable water data into DUERS (MCIWEST, 2012).

As part of EO 13514 and 13693, federal agencies are required to conserve and protect water resources through stormwater management. One of the ways this can be satisfied is through implementing and achieving the objectives identified in the stormwater management guidance prepared by the EPA for compliance with Section 438 of the Energy Independence and Security Act of 2007 (EISA). Section 438 of EISA specifically calls for any federal developments or redevelopments with a footprint exceeding 5,000 square feet to maintain or restore pre-development hydrology (EPA, 2009).

EO 13693 also requires federal agencies to divert at least 50% of non-hazardous solid waste and construction and demolition materials and debris from landfill waste-to-energy disposal:

"(i) "divert" or "diverting" means redirecting materials from disposal in landfills or incinerators to recycling or recovery, excluding diversion to waste-to-energy facilities.

DoD Directives

DoD and the individual Services have published many directives, orders, and guidance documents regarding development and management of energy and water utilities, environmental management, and waste management, recycling, and disposal. Some of the ones that pertain to the types of collaborative projects discussed herein are described below.

Low Impact Development (LID), also called "green infrastructure," is a stormwater management strategy for maintaining or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives and fulfill environmental regulatory requirements. LID employs a variety of natural and manmade features that reduce the rate of runoff, filter out pollutants, and facilitate the infiltration of water into the ground. By reducing water pollution and increasing groundwater recharge, LID helps to improve the quality of receiving surface waters and stabilize the flow rates of nearby streams [DoD, 2004]. In 2004, DoD published the Unified Facilities Criteria (UFC) Design: Low Impact Development Manual which presents guidelines and a series of Integrated Management Practices (IMPs) for LID planning and design to support a facility's regulatory and resource protection programs.

DoD issued Directive 4715.21 Climate Change Adaptation and Resilience effective January of 2016. This directive establishes policy and assigns responsibilities to provide DoD with resources necessary to assess and manage risks associated with the impacts of climate change.

State Legal and Regulatory Requirements

In addition to the national environmental laws and regulations, the Mojave installations must comply with federal laws that are implemented via state programs, as well as some state and local regulations.

Portions of the SDWA and CWA are implemented via State and local regulations, so installations in California must establish water quality management programs in accordance with California State Water Resource Control Board (SWRQB) policies and regulations, which are in turn implemented via the nine Regional Water Quality Control Boards (RWQCB).

In 2014, California passed the Sustainable Groundwater Management Act (SGMA) to ensure a reliable water supply for California into the future. The SGMA provides a framework for sustainable management of groundwater supplies by local authorities, with a limited role for state intervention only if necessary to protect the resource. The act requires the formation of local groundwater sustainability agencies (GSAs) that must assess conditions in their local water basins and adopt locally-based management plans. The act provides 20 years for GSAs to implement plans and achieve long-term groundwater sustainability (CA DWR, 2014).

In keeping with the high value placed on "alternative" water resources within arid regions, the California SWRCB adopted the *Recycled Water Policy* in 2009 (amended in 2013) to increase the use of recycled water from municipal wastewater sources as an alternative to potable water for approved demands. In addition to setting guidelines for use of recycled water and captured stormwater, this policy requires that salt and nutrient management plans be developed for all groundwater basins within California (as a means for managing the loading of salts and nutrients that occurs with recycled water irrigation and aquifer injection) (CA SWRCB, 2013).

In 2014, California passed AB 1826, requiring the diversion of organic materials, including food waste, green waste, landscape and pruning waste, nonhazardous wood waste, and food-soiled paper waste that is mixed in with food waste by commercial and public entities – including federal facilities and agencies.

Water Rights

Installations also manage water resources under state water rights programs. The California SWRCB administers water rights according to state statutes based on the riparian and prior appropriation doctrines. Riparian rights are rights to divert, use and enjoy waters from a stream that abuts one's property. Riparian rights are held in common by all the land owners along a stream or river in California. They have "correlative rights" with respect to each other; that is, they own a right to use a percentage of the flow of the stream every year, a percentage which doesn't change. In dry years, however, they must take less from the stream, according to the riparian doctrine.

Under the prior appropriation doctrine, the priority of water rights is generally considered to be "first in time, first in right"; older water rights are given seniority over junior rights. Those who put the water to use first are senior water rights holders and those who come later hold junior rights. As an example of the manner in which this operates, if a junior user is upstream from a senior user, the junior user must leave enough water in the stream to fulfill the senior user's rights. An exception to this rule is Federal Reserve Rights (which pertain to some installations) that establish the priority of the right to be consistent with the date when the land was withdrawn from public use for federal purposes. The intent of federal reserved rights is to provide water to the installation in order to satisfy both existing and future uses for which the land was withdrawn from the public. The quantification of federal reserved water rights generally occurs during judicial proceedings such as an adjudication.

Appendix B Department of Defense Installation Site Visits and Personnel Interviewed

This Appendix provides supplementary information regarding the EPA/ORD team site visits to the Mojave DoD installations.

Fort Irwin

The site visit occurred on December 3, 2015. The EPA team consisted of:

- Jose Zambrana, Ph.D. - Senior Science Advisor in the Immediate Office of the Assistant Administrator, US EPA Office of Research and Development
- Ardra Morgan - Program Manager for Net Zero & Net Positive Partnerships, National Exposure Research Laboratory, U.S. EPA Office of Research and Development
- Stephen Kraemer, Ph.D. - Research Hydrologist, US EPA National Exposure Research Laboratory Ecosystems Research Division
- Kate Helmick - ORISE Fellow for Net Zero/Net Positive Initiative, National Exposure Research Laboratory, U.S. EPA Office of Research and Development
- Scott Thomas, Ph.D. Supervising Scientist, Stetson Engineers

The team provided an in-brief with Mr. Muhammed Bari, P.E., Director Public Works, followed by discussions with staff regarding the installation's needs and challenges in water management and presentation of potential EPA technology demonstrations. Personnel at the meeting included Mr. Bari, Chris Woodruff (Water Resources Manager, DPW), Mr. Thomas Rodriguez (IMCOM Environment Management, San Antonio, TX), Yogi Patel (Army Corps of Engineers, Rock Island District), Ken Berg (POC for Stormwater Management, Engineering Division).

Following the meetings, Mr. Woodruff took the EPA team on a tour of Fort Irwin. Following the tour, the team discussed the issues and challenges facing Fort Irwin and discussed several potential demonstration projects that could be pursued, followed by an out-brief with Mr. Bari.

Marine Corps Air Ground Combat Center

The site visit occurred on December 7, 2015. The EPA team consisted of:

- Jose Zambrana, Ph.D.
- Kate Helmick
- Scott Thomas, Ph.D.

The team provided an in-brief with Lieutenant Colonel Tim Pochop, Director Natural Resources and Environmental Affairs; Lieutenant Commander James Stewart, Assistant Public Works Officer; Mr. Chris

Elliott, Water Resources Manager; and Mr. Mike Henderson , Wastewater Treatment Plant Operator. Following the in-brief, the group went on a van tour of the Mainside area of MCAGCC. Following the tour, the team discussed the issues and challenges facing MCAGCC in water, energy, and waste management. The group discussed several potential EPA demonstration projects that could be pursued.

Edwards Air Force Base

The site visit occurred on December 10, 2015. The EPA team consisted of:

- Jose Zambrana, Ph.D.
- Stephen Kraemer, Ph.D.
- Scott Thomas, Ph.D.

The team provided an in-brief with James Judkins, Director of the Civil Engineer Group; Herbert Roraback, Environmental Management Division Chief; Tom Rademacher, Conservation Chief; Scott Kiernan, Sustainability Officer/Encroachment Prevention Management; Gerald Boetsch, Energy and Utilities Manager; Andrea Brewer-Anderson, Environmental Special Projects Manager; Dan Reinke, Principal Scientist Conservation; Misty Hillstone, Natural Resources Manager; John Shartzer, Water Shop; and Richard Morris (Energy Shop).

Following the in-brief, the team discussed the issues and challenges facing Edwards AFB in water, energy, and waste management. The group discussed several potential EPA demonstration projects that could be pursued. Following the meeting, the group went on a van tour of the Base to view sites with special challenges and potential project sites.

Marine Corps Logistics Base Barstow

The site visit occurred on April 20, 2016. The EPA team consisted of:

- Jose Zambrana, Ph.D.
- Scott Thomas, Ph.D.

The team provided an in-brief with Vicki Davis, Environmental Program Analyst, Installations & Logistics; Major Stacey Colon, Deputy Director, Environmental Division; Tony Mesa, Energy Manager (I&L); Mark Ulibarri, Water Programs Manager (Environmental); and Freezy Smalls, Depot Risk Management Division Head.

Following the in-brief, the team discussed the issues and challenges facing MCLB Barstow in water, energy, and waste management. The group discussed several potential EPA demonstration projects that could be pursued. Following the meeting, the group went on a van tour of the Nebo and Yermo Areas of the Depot to view sites with special challenges and potential project sites.

China Lake Naval Air Weapons Station

The site visit occurred on April 21, 2016. The EPA team consisted of:

- Jose Zambrana, Ph.D.
- Scott Thomas, Ph.D.

The team met with Bob Campos (Utilities Director) and Randy Wood (Contractor – Resource Efficiency) to discuss the issues and challenges facing China Lake NAWS in water, energy, and waste management. The group discussed several potential EPA demonstration projects that could be pursued. Following the meeting, the group went on a van tour of the Station to view sites with special challenges and potential project sites.

Following the tour the team conducted an out-brief with CDR Brian Longbottom (Public Works Officer) and his staff.

Appendix C EPA Research Objectives

The issues addressed within this report align with several of EPA's research objectives and research topics as published in Strategic Research Action Plans (StRAPs). Relevant objectives and topics are presented in the table below.

Program	StRAP Research Objectives and Topics Aligned with this Research
Safe and Sustainable Water Resources	**Research Objectives:**
	Transform the concept of waste to resource
	Translate research into real-world solutions
	Research Topics:
	Watershed Sustainability
	Green Infrastructure
	Water Systems
Sustainable and Healthy Communities	**Research Objectives:**
	Develop the data, models, and tools to expand community stakeholders' capabilities to consider the social, economic, and environmental impacts of decision alternatives on community well-being, and to support the next generation of environmental scientists.
	Develop the causal relationships between human well-being and environmental conditions and the tools and metrics that allow assessment and tracking of progress.
	Provide research and technical support for cleaning up communities, ground water, and oil spills; restoring habitats and revitalizing communities; and advancing sustainable waste and materials management.
	Develop a Sustainability Assessment and Management Toolbox to help the Agency and others build sustainability into day-to-day operations.
	Research Topics:
	Decision support and innovation
	Community well-being: public health and ecosystem goods and services
	Sustainable approaches for contaminated sites and materials management

	Sustainable Materials Management
	Integrated solutions for sustainable communities
	Case studies
Air, Climate, and Energy	**Research Objectives:**
	What are effective preparedness and adaptation strategies to mitigate air pollutant and climate impacts, focusing on at-risk individuals, communities, and ecosystems?
	What innovative preparedness methods are needed to effectively inform individual- and community-level adaptation to climate change and decision making regarding air quality?
	Research Topics:
	Climate Impacts, Vulnerability, and Adaptation (CIVA)
	Sustainable Energy and Mitigation

Appendix D Prospectus for a Potential Project at Ft Irwin

Innovative water management for drought resiliency in the arid southwestern USA

Survival is the ability to swim in strange water.

--- Frank Herbert, Dune

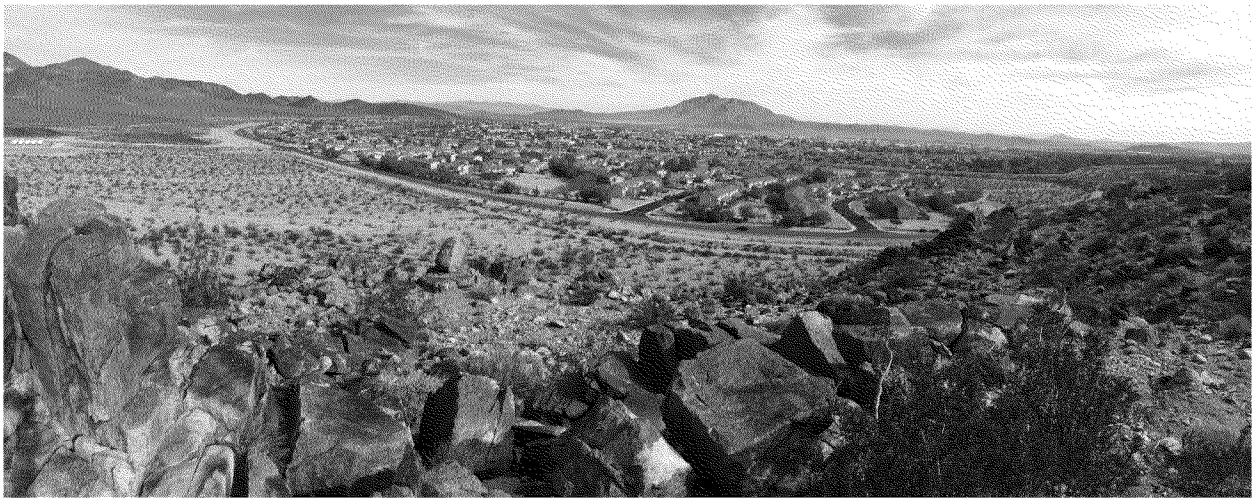
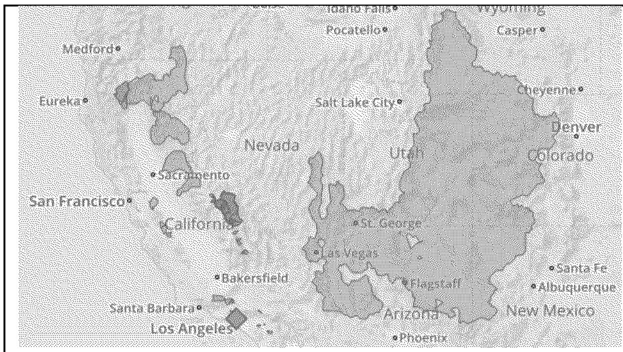


Figure B- 1. The National Training Center located at Ft. Irwin, in the Mojave Desert of Southern California.

The availability and reliability of drinking water for human developments is critical for healthy economies and human welfare, especially in the arid southwest USA. Communities range in size from military installations (Ft Irwin) to mega cities (Los Angeles). Clean water sources include stores (snow pack, aquifers, reservoirs) and flows (aqueducts, treated wastewater, desalination of sea water, stormwater runoff). Water use efficiency may be considered a source, including reduced water distribution pipe losses and efficient household water use. Many of these sources are sensitive to changes in climate, and mega droughts are entering into the realm of future possibilities. Most of California remains in a historic drought after four years of decreased precipitation and higher temperatures. The potential for winter rains associated with the current El Niño in the Pacific Ocean is greatly anticipated. A sustainable future for the LA Basin in terms of drinking water infrastructure will require improvements in water use efficiency, increased recycling, and development of new sources, such as diverted stormwater runoff into the storage capacity of the basin aquifers, provided water quality could meet requirements. Los Angeles water supply resiliency would benefit from increased use of local sources of water, such as the subsurface aquifers, especially given the reality of decreased imported supply in the future.

The National Training Center at Ft. Irwin (population 8,000-16,000) is located in the Mojave Desert region of southern California and has a sole source of drinking water from the aquifers beneath the installation and aquifers in close proximity. The existing and long-term mission is dependent on an adequate and reliable source of drinking water. When it does rain, the rate and volume of precipitation is significant, resulting in dominant overland flow through washes outside of the developed area, and damaging uncontrolled flooding in the permanent cantonment area. Control and treatment of parts of these storm flows through innovative LID or BMPs might provide a much needed source of water for recharge of the drinking water aquifers. Examples of innovative LID/BMPs include dry wells and infiltration galleries.



Los Angeles Water Supply

Figure B-2. Los Angeles relies on watersheds and structural diversions for most of its water supply. Increased sourcing from local groundwater aquifers would improve resilience under drought conditions.

A research project is envisioned which, in cooperation with extramural partners, would investigate resilient water management under drought conditions through innovative LID/BMPs designed, built, and monitored at Ft. Irwin, and positioned for technology transfer to the greater Los Angeles basin. The design and evaluation phase, funded with existing EPA resources, would be conducted in partnership with the USDA ARS Southwest Watershed Research Center (Tucson, AZ) and ARS Soil Salinity Laboratory (Riverside, CA), and would utilize existing models and available data. The build phase of the LID/BMPs would require funding support from the U.S. Army program in Energy and Sustainability (Marc Kodack, Washington, DC). The water quality monitoring program before and after the build phase would probably require additional resources from EPA to mobilize the groundwater field crew (Ada, OK) and perhaps the surface geophysics team (Las Vegas, NV). Significant findings would be shared with Ft. Irwin and other Mojave installations to better inform their resilience-building efforts. They would also be reported in peer-reviewed journal articles. Finally, EPA reports would be generated to communicate technology transfer of relevance to cities like Los Angeles.